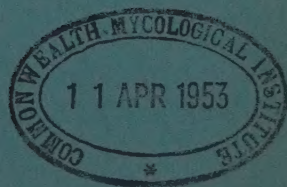


ENDEAVOUR



Volume XII Number 46

APRIL 1953



The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus

ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

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Archaeology and the other sciences

After a considerable period in which the sciences were closely interwoven there began, some century and a half ago, a long period of divergence in which the principal branches, notably physics, chemistry, and biology, developed to a great extent independently. So pronounced was this independence that it even became fashionable for scientists of one persuasion to affect complete indifference to the work of their fellows in other fields. Although this attitude is still by no means unknown, there has been in recent years a very marked tendency for science to become unified once again, instead of being a collection of largely independent disciplines. There can, of course, be no return to the days in which a man could take the whole of science as his province and make major contributions in several different fields of it; today the accumulation of knowledge is so vast that specialization is inevitable. The process of unification now occurring is manifested by the active collaboration of different specialists in teams, and by an increasing tendency for the individual to follow new discoveries in fields other than his own in order to see what benefit he may derive from them himself and, conversely, whether his own knowledge and techniques can be applied in them. The wide efflorescence of this new spirit, and the abandonment of the old attitude of indifference, is one of the most important developments in science during the present century.

In no branch of science is this process of anastomosis more fully developed than in archaeology. While this science has many techniques of its own, such as the systematic classification of the characteristics of ancient cultures, it makes use of many extraneous ones. The modern archaeologist presses into his service such diverse sciences as astronomy, botany, chemistry, geology, and physics.

The science of petrology has proved of particular value to archaeology. For example, consideration of the nature of certain Neolithic stone axes found at many places in Britain indicated that the factory supplying them must have been located at a certain spot in Westmorland, for only there does that particular stone outcrop. Field-investigation revealed the factory at precisely the point predicted. By the same reasoning, other ancient axe-factories have been located or postulated in Wales, Cornwall, and Northern Ireland. The distribution of axes derived from these specific sources gives valuable information about

ancient trade-routes. Similarly, the origin of the 'blue stone' monoliths at Stonehenge has been proved to be some two hundred miles away in Wales. In Angola, archaeology has been able to contribute to petrology, for the presence or absence of human implements has been used as an important criterion for distinguishing diamantiferous from other gravels.

No less important than the careful excavation of objects of archaeological significance is their restoration or preservation against further decay. In this field chemistry has made important contributions, largely through the initiative of Flinders Petrie. These chemical processes first attracted attention in connection with the contents of Tutankhamun's tomb, and later of that of Hetepheres, mother of Khufu or Cheops. The treatment of the rich archaeological treasures of the Sutton Hoo burial-ship is still providing much restoration work for the laboratories of the British Museum.

The value of aerial photographic surveys in archaeology is now generally known. Large buried objects, such as roads or walls, or sites of ancient soil disturbances, are often very clearly revealed by crops at certain stages of their growth. Again, certain plants show a marked preference for silted-up ditches; at least one prehistoric settlement has been revealed by the ring of poppies growing in the old rampart-ditch.

It should not be thought that archaeology profits from other sciences and gives nothing in return. On the contrary, archaeology has reciprocated handsomely, and is clearly capable of contributing much more. Thus discoveries by archaeologists of identifiable animal and plant remains sometimes furnish the biologist with new information on the former distribution of certain species. For example, recent excavation of a first-century site in Yorkshire yielded a beetle of a species now known in England only in the south. It seems likely, too, that full investigation of available archaeological data would increase our knowledge of the evolution of domesticated animals.

Especially interesting is the light which archaeological investigation has thrown upon the corrosion of metals. Recent excavations at Hungate, in Yorkshire, yielded ancient articles of iron, wood, and leather in an exceptional state of preservation; the iron, in particular, was never rusty but was coated with a dark film of grey, black, or blue. Analysis showed the surrounding soil to be

unusually rich in phosphate and tannate, and it appears that the preservation of the iron was mainly due to the inhibitive effect of tannate on sulphate-reducing bacteria which, although present in the soil, were inactive. The practical possibilities of this discovery are now being considered; they may well be important, for in Britain alone the corrosion of buried iron pipes costs some five million pounds annually.

The principal task of archaeology is to date the objects uncovered by excavation. Indirect evidence often enables approximate, and sometimes very accurate, estimates to be made, but there are many instances in which only a direct approach is feasible. Happily, several new techniques have been developed for this purpose, valuable both in themselves and in checking other methods.

A geological method of dating archaeological remains is based on counting the varves or laminations found in clay deposits at the bottom of glacial lakes. From a datum-point at Ragunda in Sweden, which could be precisely dated as A.D. 1796, de Geer was able to find a continuous succession back to 7912 B.C.; he has since carried the succession back to a total of some 17,000 years, but errors and omissions in the later data, which do not of course invalidate the fundamental soundness of the method, limit their usefulness.

From botany, too, the archaeologist derives valuable support in solving this vital question of dating excavated objects. Lennart von Post showed that waterlogged deposits, especially peat, preserved the membranes of pollen grains trapped in them as they were laid down. He realized that an analysis of these grains can give an indication of the composition of contemporary forests, which in turn gives information about major climatic changes, the dates of many of which can be deduced from other evidence. (See Godwin, A. H., *ENDEAVOUR*, 10, 5, 1951.)

Chemistry offers a method of dating based upon the fluorine content of bones, which increases with age owing to the conversion of hydroxy-apatite into fluor-apatite by fluorine present in soil-water. This method, devised many years ago by A. Carnot, confirmed the dating of the Swanscombe skull and disproved that of the Galley Hill skull.

Of the new techniques of dating the newest and perhaps the most striking is that developed some four years ago by Professor W. F. Libby of Chicago. Briefly, it depends upon the fact that all living organisms contain a uniform proportion of radioactive carbon (C^{14}), probably derived from the bombardment of nitrogen in the upper layers

of the atmosphere by cosmic rays. When the organism dies, equilibrium between C^{14} in the body and atmospheric C^{14} , normally maintained by respiration, is upset. The radioactive carbon in the dead organic matter immediately begins to decay at a steady rate, corresponding to a half-life of about 5700 years. Hence the amount of radioactivity remaining in such material as wood-charcoal obtained from excavations is a direct measure of its age. The radiocarbon method carries us back to approximately the last phase of the Ice Age, and within this range gives, provided certain essential precautions are observed, a date accurate to within a few hundred years. The method will be fully described by Professor Libby in a forthcoming issue of *ENDEAVOUR*.

The three principal techniques just described—estimation of radiocarbon, varve-counting, and pollen-analysis—give their most accurate results for the millennia following the last Ice Age. Their sensitivity is least for the two most recent millennia, but happily botany can offer yet another method, that of dendrochronology, which is most effective during precisely this period. This method was devised by A. E. Douglass and depends upon the counting and measurement of the annual growth-rings in timber. Starting from a known reference date, a series has been constructed back to about A.D. 400. As some of the giant sequoias of California are at least three thousand years old, it may ultimately be possible to extend the series still further. A remarkable feature of this method is that it gives the date of the cutting of timber, used for such objects as beams and door-posts, accurately to a single year. From its very nature dendrochronology must be either very precise or worthless. It should be understood, however, that this method is applicable only for countries which have, or have had, regular annual fluctuations of climate sufficient to be reflected in the growth-rings of trees. So far, the series has been worked out only for America; attempts to build up a European series have not been satisfactory.

As has been said, the healthy relationship between archaeology and the other sciences illustrates a trend in science as a whole, a trend which deserves the fullest encouragement. While many of the great discoveries of recent years have been due to the combined efforts of many specialists, the necessary co-operation has often been contrived only with difficulty. Although such collaboration is today generally approved, its more effective organization is desirable and could not fail in the long run to be very fruitful.

Tracer technique in biosynthesis

J. W. CORNFORTH

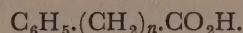
Preoccupation with the military aspects of recent developments in nuclear physics has tended to mask their immense importance in many different fields of research. The relative abundance of radioactive isotopes provides, however, a means of analysing many processes too complex to be followed in other ways. Both radioactive and non-radioactive tracers have been useful in elucidating the successive stages of important biosyntheses, such as photosynthesis and the formation of steroids. The impetus thus given to research is unlikely to slacken quickly.

Biosynthesis is a process by which a living organism builds simple molecules into more complex ones. It is only in recent years that the study of biosynthesis has made appreciable progress, for the initial difficulties are formidable. Comparing the chemical composition of an animal with that of its normal food will usually leave one no wiser than the farmer, who knows that his sheep turn grass into wool and mutton. It is certainly possible to deduce more than this; for example, by feeding an animal for a time on a fat-free diet it can be shown that some of the carbohydrate consumed must have been changed into fat. Such methods, however, reveal little about intermediate stages in the transformation, and diets of known composition have been useful mainly in identifying substances which an organism requires but may not be able to synthesize for itself.

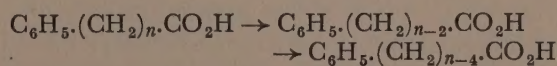
A refinement of this approach, opening a fruitful line of inquiry, was introduced in 1941 by Beadle and Tatum. One chooses an organism—the mould *Neurospora* is the classical example—which will grow on a simple medium of strictly defined chemical composition. The organism is then maltreated in various ways—by exposure to X-rays, for instance—which are likely to cause mutations in its genetic make-up. Mutant strains may thus be produced which are congenitally incapable of carrying out some particular stage in the biosynthesis of an essential metabolite. Such strains grow normally if the usual medium is enriched either with the metabolite itself or with any intermediate which comes after the genetic block in the series of biosynthetic reactions. In addition, the intermediate substance coming immediately before the genetic block will often accumulate in the medium, the organism being able to synthesize it but not to transform it further. With a series of such mutant strains, each blocked at a different point in a particular biosynthesis, it is sometimes possible to follow the synthetic process in consider-

able detail. The method is limited to small species which grow and reproduce rapidly, and which are not exacting in their food-requirements. Naturally, there is no control over the type of mutation induced, so that the sorting-out of new strains is a tedious business. Within these limitations most valuable results are none the less being obtained.

An entirely different way of attacking the problem involves the use of labelled atoms and molecules. The work of Knoop (1905) on the oxidation of fatty acids in the body may be viewed as an early attempt to use this approach. He administered to animals a series of synthetic acids which differed from normal fatty acids, $\text{CH}_3(\text{CH}_2)_n\text{CO}_2\text{H}$, in having a terminal phenyl group:



The phenyl group, not readily destroyed in the body, was the label. When the number n in this labelled fatty acid was even, the final product of oxidation (excreted in the urine) was benzoic acid, $\text{C}_6\text{H}_5\text{CO}_2\text{H}$. When n was odd, the end-product was phenylacetic acid, $\text{C}_6\text{H}_5\text{CH}_2\text{CO}_2\text{H}$. The natural inference was that oxidation of these acids (and hence presumably of the normal fatty acids) is initiated on the carbon atom next but one to the carboxyl group (the β carbon atom), the course of the oxidation being



and so on, until a β — CH_2 group is no longer available. However, the breakdown of these unnatural fatty acids cannot strictly be called a normal metabolic process, and it would be much more difficult to devise adequate model substances for most biochemical reactions. What one needs is a way of specifically labelling a molecule without changing any of its chemical properties. This can be done with the help of isotopes.

It is well known that most chemical elements

occur naturally in more than one isotopic form. In an average specimen of carbon most of the atomic nuclei have six protons and six neutrons, but a small proportion (about one in ninety) have six protons and seven neutrons. The lighter atoms are called C^{12} and the heavier C^{13} . In a qualitative sense, these two varieties of carbon atoms are chemically indistinguishable. No ordinary chemical operation will enrich one or the other to a significant degree. They do, however, differ very slightly in the speed with which they undergo chemical reactions, and by using the principle of the fractionating column it is possible to exaggerate this difference and gradually to obtain a partial separation. Slight differences in physical properties also exist, and an equally laborious separation may be based upon them. By such physical or chemical procedures, specimens of hydrogen, carbon, nitrogen, oxygen, and sulphur have been prepared which contain an abnormally high proportion of the heavier isotopes. The relative abundance of the different isotopes in a particular specimen can be measured with considerable accuracy by the mass spectrometer.

In the special case of the hydrogen isotopes protium, H^1 , and deuterium, H^2 , the difference in density between light (H^1_2O) and heavy (H^2_2O) water is sufficient to be used for the estimation of the deuterium content (for example, by measuring the rate at which a standard-size drop of the water falls through a liquid of almost the same density).

With the development of the nuclear reactor for uranium fission, with its intense neutron flux, it became possible to produce radioactive isotopes in quantity. Long-lived radioactive carbon (C^{14}) is now the customary isotope for labelling carbon compounds. It is made by exposing nitrogen (N^{14}) nuclei to neutron bombardment: a neutron is captured, a proton expelled. Nuclei of C^{14} are only slightly unstable: the half-life period is about 5700 years. When a C^{14} nucleus decays, a β -particle is emitted and N^{14} is regenerated.

By similar procedures, radioactive isotopes of phosphorus, sulphur, iron, and several other biologically important elements may be produced. In tracer studies with oxygen and nitrogen, however, one must still depend on the stable isotopes separated by fractionation methods.

Special techniques are required when working with radioactive material. Isotopes emitting γ -rays must, unless the quantity involved is small, be manipulated behind lead screens. The less penetrating β -radiation is usually stopped by the

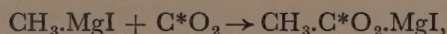
laboratory glassware used to contain the material. Great care must always be taken to avoid spilling solutions or powders, and to dispose safely of waste products; this is necessary not only because of possible danger to health, but because contamination of samples may occur and lead to false measurements of radioactivity.

The great advantage of radioactive isotopes is the ease with which they may be detected and estimated. A Geiger-Müller counter can register the radioactive decay of a single nucleus, hence only a small degree of radioactivity in the sample is necessary. The Geiger counter is the basis of most of the measuring apparatus used, and may be employed with solid, liquid, or gaseous samples. The penetrative power of the radiation has to be considered in designing an apparatus for analysis of a particular isotope. Solid samples containing C^{14} are spread on disks of standard size and shape, which are then placed inside a heavy shield at a fixed distance from the counter. The disintegrations registered are counted automatically, and instruments have been designed to count several successive samples without attention. Corrections are applied for the count due to adventitious radiation recorded when no radioactivity is present in the sample, and for absorption of radiation by the sample itself. A result is often expressed in counts per minute per milligram of carbon present, and this is directly proportional to the concentration of isotope. Radioactive decay being a random process, it is necessary to continue the counting long enough to eliminate statistical fluctuations.

The application of isotopes as biochemical tracers is, in principle, quite simple. Given an isotope-enriched sample of a biologically important element, one uses it in the synthesis of some substance normally assimilated by the organism being studied. Having introduced this labelled substance into the organism, one can examine the excretion of the isotope and its distribution in various constituents of the tissues, with the assurance that the labelled molecules have been taken through normal metabolic processes.

Isotopically enriched material is usually supplied in a simple chemical form, e.g. C^{14} as barium carbonate, N^{15} as an ammonium salt, and so on. The building-up of an isotopically labelled molecule differs in some interesting ways from ordinary organic synthesis. The isotope is always the most valuable ingredient, and the method has to be chosen—or invented—so that it is introduced at as late a stage as possible, and that a minimum of

loss occurs in any subsequent stages. In planning an ordinary total synthesis the chemist can use a quite complex starting-material, provided that someone has previously synthesized it, but when isotopes have to be incorporated such earlier steps cannot be taken for granted. Great trouble must sometimes be taken to prepare substances which in the ordinary way would simply be taken from the laboratory shelves. Suppose one has the problem: given a specimen of C^{14} -labelled barium carbonate, to prepare two specimens of acetic acid, $CH_3.CO_2H$, one labelled in the carboxyl group and the other in the methyl group. Carbon dioxide is liberated from the barium carbonate with acid, and half of it is condensed, with the help of liquid air, in a tube containing methyl magnesium iodide solution. On warming to 0° , the following reaction takes place (C^* signifies the labelled carbon atom):

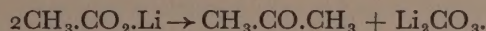


and, on decomposition with acid, carboxyl-labelled acetic acid $CH_3.C^*O_2H$ is liberated. The other half of the carbon dioxide is hydrogenated catalytically at high pressure to methanol, $C^*H_3.OH$; this is converted through methyl iodide, $C^*H_3.I$, to methyl magnesium iodide, which is made to react as above with ordinary, unlabelled CO_2 to obtain methyl-labelled acetic acid, $C^*H_3.CO_2H$. Again, when making an amino acid, $R.CH(N^*H_2).CO_2H$, labelled with N^{15} , a good procedure is to reduce an α -ketonic acid, $R.CO.CO_2H$, with hydrogen in the presence of isotopic ammonia, N^*H_3 : this method has the advantage of introducing the isotope at the last stage.

A naturally occurring substance may be too complex to prepare conveniently, or at all, in labelled form by total synthesis. In such a case one may occasionally effect an exchange of atoms, as when palmitic acid labelled with deuterium is prepared by heating the normal acid with heavy water and a platinum catalyst. Failing this, one can allow a living organism to synthesize the the labelled substance by providing the isotope, suitably combined, in its food: here, of course, there is less control over the positions of the labelled atoms in the molecule.

When a substance has been biosynthesized from an isotopic precursor, it is often important to determine the isotopic content of particular atoms in the molecules, and thus to discover the extent to which these atoms are derived from the labelled source, or sources, in the precursor. Degradation

of an organic substance is the normal way of elucidating its structure; the object is to split off, by easily interpreted reactions, identifiable pieces of the molecule—the larger the better. This new requirement of determining individual atoms often necessitates development of different procedures. To continue an earlier illustration, one may pose the problem: given a specimen of isotopic acetic acid, to determine the labelling in each of its carbon atoms. Preferably, the lithium salt is prepared and heated, when acetone distils over and a residue of lithium carbonate, originating from the carboxyl group, remains:



With sodium hypoiodite the acetone yields acetic acid and iodoform, CHI_3 , derived from the methyl groups of the acetone and hence of the original acetic acid. If the label is C^{13} , the lithium carbonate and the iodoform are converted (by acidification and combustion respectively) to CO_2 for examination in the mass spectrometer; if C^{14} is present the CO_2 is converted into a solid (barium carbonate) for counting.

Much of the early work on biosynthesis was done with isotopic hydrogen and nitrogen, since these were the first biologically important elements with which large-scale separation of isotopes was achieved. The most striking discovery of this period was what Schoenheimer called the dynamic state of body-constituents. The chemical composition of a fully grown animal being nearly constant, one would naturally assume that its food is mainly consumed as fuel to provide heat and energy, a smaller amount going to replace wear and tear of the tissues. This picture was altered even by Schoenheimer's first experiments: when fatty acids labelled with deuterium were fed to an animal, a large proportion of them rapidly appeared in fat-deposits all over the body. Moreover, when the isotope was administered in one particular fatty acid, the deuterium was distributed over nearly all the other acids found in the body-fat. Similar experiments with other food materials showed that the tissues of the body are continually being broken down and renewed. Instead of picturing a living organism as a self-repairing engine, one may rather liken it to a reservoir used to generate electric power—the water flowing into the lake becomes more or less mixed with what is already there before it goes through the turbines or over the sluices. Another and more truthful analogy is with a reversible chemical reaction; this may on balance be proceeding in one direction, but at any

moment there are some molecules undergoing the reverse process, and when equilibrium is reached it is only because the forward and backward reactions are running at the same speed.

This rapid and ceaseless flux within a living organism is one of the difficulties which confront the study of biosynthesis. The three major organic constituents of an animal body—protein, fat, carbohydrate: all relatively large molecules—are not only in dynamic equilibrium with food materials, but with each other. Isotopic carbon fed in the form of sugar appears in body protein and fat, as well as in carbohydrates. Hence it is often important to analyse the body-tissues for isotope as soon as possible after incorporation, and before the label is too widely distributed.

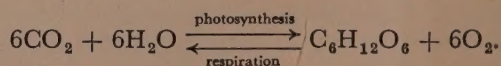
The large molecules of the body are broken down into small units for re-synthesis. The actual quantity of these small molecules present in the tissues at a given instant is often quite small. One of the key intermediates in animal metabolism is acetic acid, yet so transient is its existence in the living body that indirect methods are needed to detect it. When isotopically labelled acetic acid is absorbed by the organism, it is mixed with the momentarily existing metabolic reservoir of acetic acid which is constantly being depleted by the synthesis, and replenished by the breakdown, of other molecules, especially fats. If at the same time the organism is fed with a suitable amine which is not a normal body constituent, part of the acetic acid pool is used to acetylate it, and the amine is excreted as the acetyl derivative in the urine. Sulphanilamide is satisfactory for the purpose: it is excreted as N-acetylsulphanilamide, $\text{CH}_3\text{CO.NH.C}_6\text{H}_4\text{SO}_2\text{NH}_2$, a substance easy to isolate and to hydrolyse back to sulphanilamide and acetic acid. The acetic acid recovered in this way can be examined for isotopic content. The proportion of isotope in the recovered acetic acid depends on (a) the amount of metabolic acetic acid with which the labelled dose became mixed, and (b) the rate at which it is disappearing and being replaced. By setting up a series of experiments and extrapolating to zero time, one may form estimates of both these factors, and hence of the importance of acetic acid as an intermediate in biosynthesis. Rittenberg and Bloch have estimated in this manner that the rat produces about 1 g of acetic acid per day per 100 g body-weight.

When carrying out an experiment of this kind it is necessary to make sure that the substance isolated from the organism, and also, of course, the substance administered, are free from impurities

which might themselves have a higher isotopic content. This is particularly important when the proportion of isotope is small. Crystallization of a labelled organic substance to constant radioactivity is better than the ordinary purification to constant melting-point. When a metabolite can be isolated only in small quantity it may not be easy to effect complete removal of impurities. This difficulty may often be circumvented by adding a known, larger amount of the pure non-isotopic substance, thus providing a more substantial quantity for isolation: the isotope is diluted but still detectable. In this way, it is sometimes possible to detect in a complex mixture substances which would otherwise defy separation.

THE PATH OF PHOTOSYNTHESIS

The most important biosynthetic process, so far as life on this planet is concerned, is photosynthesis, by which green plants use solar energy to fix carbon dioxide from the air. It has long been known that a green leaf exposed to sunlight will absorb carbon dioxide and liberate oxygen; that the chloroplasts of the leaf, containing the chlorophyll, are intimately associated with this function; and that atmospheric carbon dioxide is the source of carbon for all the plant's tissues. This chemical absorption of solar energy is also the basis of animal life, for though animals do not photosynthesize they obtain their food directly or indirectly from plants, and their energy by the reaction of some of this food with oxygen. The complementary nature of plant and animal life—the plant absorbing carbon dioxide and liberating oxygen, the animal doing the opposite—was also early recognized. If a leaf is starved by keeping it in the dark, and is then exposed to sunlight, the most obvious change detectable by older techniques is a renewal of the exhausted starch reserves. Thus glucose, the parent sugar of starch, is an important product of photosynthesis: the breakdown of glucose is also a major source of animal energy, and one might almost write a reversible equation:



Conversion of carbon dioxide to glucose is chemically a reduction, and there was speculation whether the process requiring solar energy was a reduction of carbon dioxide to formaldehyde, CH_2O . Some colour was given to this view by Emil Fischer's demonstration that formaldehyde can be polymerized, very inefficiently, to hexoses. It was perhaps unfortunate that an overall course

of photosynthesis could be represented so neatly, for this tended to mask the underlying ignorance of the processes involved. Only during the last dozen years have successful studies been made of the detailed mechanism; progress had to wait for the development of more powerful analytical weapons, of which isotopic carbon is the chief. One important inference had, however, been drawn without the help of isotopes: that fixation of carbon dioxide and evolution of oxygen are discrete stages. A green juice containing the chloroplasts may be prepared by macerating the green cells of a leaf. The juice can no longer fix carbon dioxide, but it still evolves oxygen in light provided that certain reducible substances are present: these are simultaneously reduced. This and other experiments led to the view (now thought to be correct) that the reaction which absorbs solar energy is not a fixation of carbon dioxide but a splitting of water molecules, the hydrogen being stored up in the reduced form (XH_2) of an enzyme system (X) while the oxygen is liberated:



The system XH_2 then takes part in the fixation of carbon dioxide. An early application of isotope technique to photosynthesis was the use of isotopic oxygen in the water, and alternatively in the carbon dioxide, supplied to a photosynthesizing plant. Such experiments showed that the evolved oxygen came from water and not from carbon dioxide. Later, when radioactive carbon dioxide became available, it could be demonstrated that a plant exposed to light in the absence of carbon dioxide can subsequently fix carbon dioxide in the dark, the power to do so lasting for several minutes.

Spectacular progress has been made in following the fate of assimilated carbon dioxide. Calvin and his associates at Berkeley, California, are prominent in this field. For this purpose, green algae are better experimental subjects than higher plants, for one can manipulate them in the form of a soup, and this facilitates efficient and uniform absorption of light and carbon dioxide. A suspension of algae (*Chlorella*, *Scenedesmus*) was illuminated and supplied (simultaneously, or later in the absence of light) with radioactive carbon dioxide. After a predetermined time, the cells were killed by dropping them into acid, and their constituents were examined. The method of partition chromatography on paper, which was being developed at about the same time, is well suited for analysing the complex mixture present in a plant. The

position of a substance in the chromatogram is a provisional guide to its identity, and the position of radioactive constituents may be found by using the old Becquerel effect—the fogging of a photographic plate held near the radioactive source. Thus an autoradiograph of the paper is obtained.

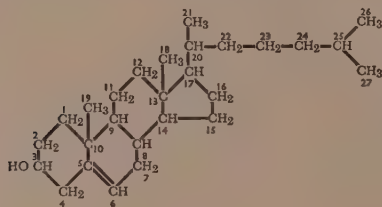
This experimental approach soon showed that the carbon of carbon dioxide, once absorbed, is rapidly distributed among a large number of plant constituents. To find out which of these is the immediate product of carbon dioxide fixation, it was necessary to reduce to a few seconds the time of contact with the radioactive gas. The absolute amount of photosynthesis occurring in this time was small, but the difficulty could be offset by using carbon dioxide of high activity. As the time of contact was made shorter, fewer radioactive spots appeared on the chromatogram, and a progressively larger fraction of the carbon fixed was found in the carboxyl group of phosphoglyceric acid, $\text{HO}_2\text{C}^*.\text{CHOH}.\text{CH}_2\text{OPO}_3\text{H}_2$: under favourable conditions about three-quarters of it could be found in this position. The necessary degradation of phosphoglyceric acid was effected by hydrolysis to glyceric acid and oxidation of this acid with periodate, the three individual carbon atoms then appearing as carbon dioxide (carboxyl group), formic acid (α -carbon), and formaldehyde (β -carbon). So fast are a plant's metabolic processes that if photosynthesis is allowed to continue for a few minutes these three carbon atoms become equally radioactive. The results obtained so far suggest that the primary fixation-reaction is between carbon dioxide and a two-carbon acceptor molecule: this latter might, for example, be phosphoglycol aldehyde, $\text{OHC}.\text{CH}_2\text{OPO}_3\text{H}_2$, and the fixation-reaction could then be written:



The rapid incorporation of isotopic carbon into the α - and β - carbons of phosphoglyceric acid must mean that the two-carbon intermediate is itself formed at an early stage of photosynthesis. Work is now in progress to elucidate the nature and mode of formation of this intermediate. It is safe to predict that more knowledge of the photosynthetic process will be added during the next two decades than was acquired over the 180 years which have passed since the first experiments. Radioactive carbon is certain to be the principal tool in this investigation, though it will no doubt be linked with more and more elaborate experimental technique.

STEROID BIOSYNTHESIS

Problems of a different kind, in which the writer is interested, are posed by the biosynthesis of cholesterol. Steroids, of which cholesterol is the archetype, can be synthesized by plant and animal tissues, and are present in most organisms, though apparently not in bacteria. In the animal body, cholesterol is an important agent in the transport of fatty acids, and is believed to be a precursor of the sex hormones (male and female), the adrenal cortical hormones, and vitamin D. The chemical structure of cholesterol was unfolded after a long series of analytical researches, and recently the substance has been synthesized in the laboratory. The four-ring pattern of cholesterol:



is the characteristic feature of steroids generally.

Our present knowledge of cholesterol biosynthesis owes much to work by Konrad Bloch of Chicago. Early experiments with deuterium as a tracer showed that acetic acid is rapidly built up to cholesterol; later work with C^{13} and C^{14} confirmed this result, and showed further that acetic acid can supply all the carbon atoms in the twenty-seven different positions required for the synthesis of cholesterol, and may thus be regarded as the fundamental building-unit of this molecule. Surviving slices of rat liver will synthesize cholesterol from a solution containing acetate, and this is a useful way of obtaining labelled, biosynthetic cholesterol for studies of the isotope distribution. Having prepared cholesterol in this way from acetic acid labelled in the methyl group, or alternatively in the carboxyl group, Bloch applied known degradation reactions to isolate a few individual carbon atoms. Some of these were radioactive, some were not, but carbon atoms which were inactive in cholesterol made from carboxyl-labelled acetate were active when methyl-labelled acetate was the precursor, and the converse was also true. This indicated that acetic acid molecules are built into cholesterol according to a definite pattern, and comparison of the radioactivity of individual atoms with the total activity of the molecule suggested that of the twenty-seven

carbon atoms in cholesterol fifteen are derived from acetate methyl groups and twelve from acetate carboxyl groups.

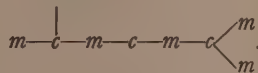
A more extensive degradation of cholesterol was then undertaken, in order to discern this structural pattern. Fortunately, the methods originally used to determine the structure of the *iso*-octyl,



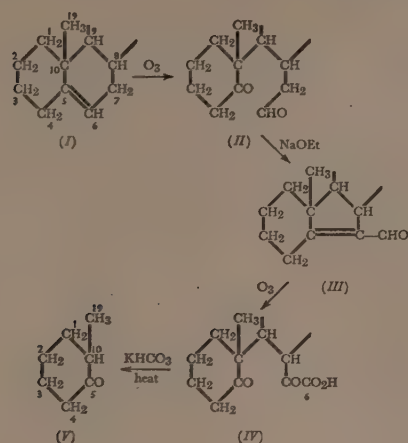
side-chain were applicable to the new purpose. Saturation of the double bond in cholesterol, and acetylation of the hydroxyl group, lead to cholestanyl acetate. This can be oxidized (though in poor yield) to acetone, $\text{CH}_3\text{CO}\cdot\text{CH}_3$, which comes from the terminal $-\text{CH}(\text{CH}_3)_2$ group. The individual carbon atoms of acetone can be separated by methods already mentioned, though it is, of course, impossible to distinguish between the two identically situated methyl groups.

In the oxidation yielding acetone, the rest of the cholestanol molecule appears as acetoxyallocholanolic acid, in which the side-chain is shortened to

$\text{CH}_3\cdot\text{CH}\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{CO}_2\text{H}$. This acid was degraded by known methods which permitted separation of the remaining carbon atoms in the chain. To summarize, three of the eight side-chain carbons were found to originate from carboxyl groups of acetic acid, and five from methyl groups. If we denote the former by *c* and the latter by *m*, the pattern in the side-chain is



In London, at the National Institute for Medical Research, Hunter, Popják, and the author have attacked the cholesterol molecule at the other end: that is, the rings carrying the hydroxyl group and the double bond. No suitable degradation being known, it was necessary to invent one, and the process chosen is shown in the partial formulae given below. The hydroxyl group in cholesterol was first eliminated by conversion to the chloride and reduction. The resulting hydrocarbon cholestene (I) was oxidized with ozone to a keto-aldehyde (II). Treatment with sodium ethoxide then gave an unsaturated aldehyde (III) which was ozonized again, the main product being an α -keto acid (IV). Part of this was heated with aniline, when the carboxyl carbon (C_6 of cholesterol) was split off as carbon dioxide. The remainder of the acid was heated strongly with potassium bicarbonate, when an expected fission of the molecule occurred and 2-methylcyclohexanone (V) was isolated.



A block of seven carbon atoms having thus been separated, the next problem was to detach these atoms from each other. With hydrazoic acid the methylcyclohexanone (V) gave a lactam (VI), which was hydrolysed to 6-aminoheptonic acid (VII). Methyl sulphate converted this amino acid to its betaine (VIII). The betaine was now heated with potassium hydroxide; an unsaturated acid (IX) would no doubt be the first product, but it is known that hot potassium hydroxide causes the double bond of an unsaturated acid to change its position. Here, it wanders along the carbon chain until it is conjugated with the carboxyl group (X); then—and not before—an oxidative fission can take place, the products being valeric acid (XI) and acetic acid. The acetic acid, containing carbon atoms 4 and 5 of cholesterol, is analysed as described before; the valeric acid is put through a degradation which we had already devised for fatty acids in general. Bromination of the acid chloride, followed by addition of *neopentyl* alcohol, gave a bromo-ester (XII); boiling diethylaniline then removed hydrogen bromide, and the resulting unsaturated ester (XIII) on heating with potassium hydroxide underwent oxidative fission, as before, to give propionic (XIV) and acetic acids. Degradation of the acetic acid in the usual way gave carbons 2 and 3 of cholesterol; the propionic acid was oxidized to acetic acid and carbon dioxide (carbon 1). Analysis of this third molecule of acetic acid gave carbons 19 and 10.

The origin of the eight carbon atoms separated by this degradation can be illustrated by the convention used above for the side-chain. Four of the atoms originate from ace-

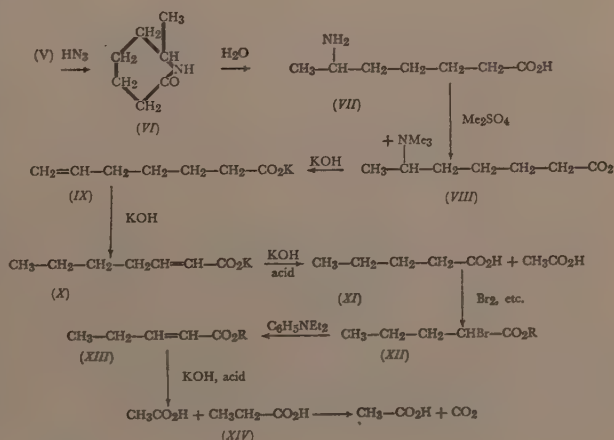
tate methyl, four from acetate carboxyl; and the pattern is:



The two degradations which have been described make it possible to examine individually the majority of the cholesterol carbon atoms for isotopic content. Plans are being laid for isolation of the remaining carbon atoms, but already any detailed theory of the biosynthesis can be searchingly tested, for it must accurately predict the positions which will be occupied by the labelled atoms when a labelled precursor is used.

From the foregoing pages several important aspects of biosynthesis have necessarily been omitted. All biosynthetic reactions, so far as is known, are mediated by enzyme systems, and long before the advent of isotopes workers were studying isolated enzymatic reactions; tracer technique has been welcomed as a powerful reinforcement. Enzyme chemistry is now moving more towards the study of co-ordinated systems of several enzymes, and biosynthetic studies help in estimating the importance of a particular system in the normal working of the organism.

An interesting possibility in this field is the emergence of biosynthesis as a serious rival of synthetic organic chemistry. In the past, a product has often been prepared synthetically more cheaply than it could be separated from living matter. Essentially, this is because the artificial synthesis is directed exclusively to a product which is only one of many components in a living organism's economy. If it becomes feasible to control metabolic processes more purposefully, this will be the fruit of increased knowledge of biosynthesis.



A Newton collection

E. N. DA C. ANDRADE

Despite the profound and enduring importance of Newton's scientific achievements there has never been a collected edition of his writings, and present difficulties make the publication of such an edition improbable in the near future. This description of a remarkable library of Newton's works, contributed by the man who formed it, is therefore of unusual historical interest, especially as the collection includes many translations and commentaries.

A passion for collecting books is like any other passion—it can be defended by reason, but it does not have its origin in reason. The true collector enjoys the sight, the feel, the smell of old books of his choosing: the learning connected with them has for him a pleasant piquancy that the knowledge connected with other pursuits does not possess. Predilection, which is the true occasioner of collecting, is no unworthy trait: in the quest for scientific discovery it is predilection that leads the man with the genuine research spirit to take up one subject rather than another, and often intuition rather than logic that leads him to conclusions, although the published account of the work is later neatly ranged by reason and set in ordered sequence by rule. I write this because I hope to justify having formed the collection of Newton books about which I am permitted here to say something, but I would not have brother collectors think that I am pretending that these were the thoughts that first prompted me to acquire an early Newton book. Reverence has something to do with it; curiosity, acquisitiveness, love of learning played their part; but the essence of the strange urge is known only to book collectors, who, like anglers, are a worthy, quiet, and congenial class of men.

It is true that Thomas Frognal Dibdin, author of the 'Bibliomania,' ridiculed the collectors of his time, but in the first place many of them collected trash whose only quality was its rarity, and in the second place Dibdin, on account of the errors with which his works abound, no longer enjoys his former authority.

A collection of Newton books has not only the interest that must attach to anything intimately connected with one of the profoundest minds that ever lived, but is necessary for anyone who wishes to study the man. The editions of his great works published in his lifetime differ from one another, and the changes and additions made often throw a significant light on the development of his

thought. The translations of Latin into English and English into Latin present points of interest, and the early posthumous editions, edited in general by accomplished scholars, are valuable for their notes. It would, of course, have been all to the good if Newton had published his work as it was carried out, but the first publication, which has in general not been reprinted, is of great significance even when it is late. Further, the work on prophecy and on chronology, although it does not touch Newton's science, is necessary if we are to understand his character, and this work exists in early editions only. Perhaps, however, it suffices to say that there is no collected edition of Newton, and the problems in the way of preparing such an edition are so formidable that in these times of scant leisure, limited funds, and rare scholarship it is doubtful if one will be produced in the near future. Other points of consequence will, it is trusted, appear as the individual works are discussed.

There are certain books connected with Newton's early life which, although not by him, should be in a Newton library. It is quite clear that the verses attributed to him by, for instance, Brewster and L. T. More [1] among others, were copied from an edition of *Eikon Basilike* [2]. My copy, in which these verses appear, is of the edition of 1649, which figures in Almack's bibliography as Item 43. No doubt the picture of Charles I which Newton made to go with the verses was copied from the folding frontispiece of this book [3]. The water-clock which Newton made corresponded closely to the picture and description in John Bate's 'The Mysteries of Art and Nature,' and the extensive rules and hints relating to drawing and painting, receipts, remedies, and so on which are entered in an early notebook of Newton's were, as I have shown, copied from the same book [4]. The first edition of this book appeared in 1634, but comparison has convinced me that the copy used by Newton was of the third edition of 1654,



FIGURE 1 – The largest-paper copy of the third edition of the *Principia*, specially bound in Harleian red morocco, which Newton presented to Littleton Powys.

which, together with the second edition of 1635, is in my collection.

The first mention in print of Newton occurs in 1669, in the preface to Isaac Barrow's *Lectiones Opticae*, as the book is usually called, although these actual words do not figure in the elaborately worded title. Here Barrow acknowledges the help of 'Isaacus Newtonus, collega noster (*peregrinae vir indolis ac insignis peritiae*)'—Isaac Newton, our colleague, a man of quite exceptional ability and singular skill. This book is bibliographically curious. The title-page gives a description of the lectures on optics, and adds '*Annexae sunt Lectiones aliquot Geometricae*'—some lectures on geometry are appended; but whereas this title-page is dated 1669 the geometry lectures have a separate title-page dated 1670. My copy of this edition (as well

as my copy of Varenus) was destroyed with my laboratory during the war. I have, however, a copy of both sets of lectures bound together, with a title-page dated 1672 tipped in, the only difference in the title being in the names of the booksellers (not printers); and another copy with a title-page, differently worded and set, dated 1674. The sheets are identical in all three editions, so that it does not really matter which copy the collector has: the different title-pages denote copies to be sold by various booksellers.

Another minor work to be mentioned before we come to the great Newton items is the 'Geography' of Varenus, which Newton edited: *Bernardi Varenii Med. D. Geographia Generalis . . . una cum Tabb. aliquot quae desiderabantur aucta et illustrata. Ab Isaaco Newton Math. Prof. Lucasiano Apud Cantabrigienses.*

Cantabrigiae MDCLXXII. Newton, writing to John Collins on 25th May, 1672, says 'The book here in the press is Varenus his Geography, for which I have described schemes, and I suppose it will be finished about six weeks hence.' From a note in the preface of the English translation of 1733 by the translator, Mr Dugdale, it appears that Newton lectured on geography while holding the Lucasian chair.

The chief items in any Newton collection must be the editions of the *Principia*—*Philosophiae Naturalis Principia Mathematica*, to give the book its full title—which first appeared in 1687. It was written by Newton in about eighteen months, as a result of Halley's urging: that the book appeared at all must be set down to Halley's credit, for it was he who first realized the supreme importance of Newton's work; it was he who agreed to 'undertake the business of looking after it, and printing it at his own charge'; and it was his tactful intervention that kept Newton, who had taken offence at certain statements of Hooke's, from suppressing the last of the three 'books' of which the work consists. Further, Halley wrote a fine laudatory poem in Latin, which is printed at the beginning of the book.

By curious fate, the title-page bears the *imprimatur* of Samuel Pepys, who was President of the Royal Society, not at the time when the book appeared, but the year before, 1686, when it went to the printer. There are two versions of the title-page: one bears the imprint *Londini, Jussu SOCIETATIS REGIAE ac Typis JOSEPHI STREATER. Prostant apud plures Bibliopolas. ANNO MDCLXXXVII*, and the other has, after Streater, *Prostant Venales apud SAM. SMITH ad insignia Principis Walliae in Coemiterio D. PAULI, aliosq; nonnullos Bibliopolas. ANNO MDCLXXXVII*. These two versions are often called, respectively, the first and the second issue of the first edition. There are, in both issues, certain misprints, such as the misnumbering of page 72 and the misprinting of the catchword on that page, which have been carefully classified. These various misprints are corrected, some or all, in some copies, but the title-pages are not tied to particular errors, and I believe that there was only one printing. It is, therefore, a mistake to speak of either the one or the other title-page as pertaining to a 'first issue.' H. P. Macomber, of the Babson Institute, Massachusetts, who has examined or had reports on twenty different copies, including my two (for I possess a copy of each issue), has also come to the conclusion that there was but one printing of the text, during which a number of errors were corrected, and that, in the

binding, the sheets with the varying corrections were gathered indiscriminately and used with the two imprints. This is in accordance with the early findings of Lord Keynes, a learned Newton scholar, who first raised the matter. The Keynes Newton collection was bequeathed to King's College, Cambridge, whose librarian, A. N. L. Munby, has published an account of it [5].

There seems little doubt that the copies with the 'Sam. Smith' imprint were for sale abroad. My copy is bound in vellum and bears the signature of Jacobus Peirce 'Lugd. Bat.,' which is *Lugdunum Batavorum*, Leyden.¹ It is by far the rarer version of the title page. Macomber, who has been for some time engaged on a census of first editions of the *Principia*, has so far listed 145 copies, of which 28 have the Smith imprint. How many copies were printed in all we do not know, but there is general agreement that the edition was small. My copy of the *plures Bibliopolas* was the property of a former Duke of Bedford, and bears his book-plate, dated 1703. It is, perhaps, equally typical that in the seventeenth and eighteenth centuries our noble families bought the great books of their time, in all branches of learning, and that in the twentieth century they got rid of them.

The second edition of the *Principia* was printed at Cambridge in 1713, and the title-page bears the well known *Hinc lucem et pocula sacra* emblem. It was edited by Roger Cotes, of whom Newton had the highest opinion—'if Mr Cotes had lived we might have known something,' said he—and is much extended in certain places. It is a quarto of the same page-size as the first, but more closely printed, so that, in spite of the extensions, it is of fewer pages. We know that the edition was 750 copies: the book is not particularly scarce, and the only difficulty is to get a good copy.

The third edition printed in England (1726) appeared in three sizes: the ordinary, which is about the same page-size as the two earlier editions, namely about 24 × 18.5 cm; a large-paper edition 28.0 × 21.6 cm as measured on my copy, which belonged to S. P. Rigaud, the Oxford astronomer and scholar, author of the 'Historical Essay on the First Publication of Sir Isaac Newton's *Principia*'; and a magnificent largest-paper, printed for presentation, of page-size 32.6 × 23.4 cm. Gray's 'Bibliography of the Works of Sir Isaac Newton,' 1907, says that only twelve copies were printed, but it has long been known that this is much less than the true number. Unexceptionable evidence

¹ Peirce was an English student of theology who matriculated at the University of Leyden in 1695.



FIGURE 2 — Plate in Colson's English translation of Newton's *Geometriae Principia*, to illustrate the principles of the calculus.

has recently been unearthed by Herbert Davis, which shows that fifty copies were actually printed, on Superfine Royal, while 200 of the large-paper and 1000 on Demy (the ordinary edition) were struck off. The binding of these largest-paper copies varies. Some of them are in sumptuous red Harleian morocco, so called because the pattern of the tooling was much used in the bindings of the great library assembled by Robert Harley, first Earl of Oxford,¹ and it may be to these that Gray refers when he says 'only 12 copies were prin-

¹ 'A shrewd and unscrupulous politician, he made a skilful party leader, but owing to his deficiency in most of the higher qualifications of statesmanship he proved a weak and incapable minister.'—G. F. Russell Baker. His love of books distinguished him from his modern counterparts.

ted, evidently for presentation.' These copies have gilt edges. Others are bound in russia, some plain, some tooled: the binding of the Babson copy is by Clarke and Bedford and so cannot be much more than a hundred years old. My copy, in the Harleian red morocco (see figure 1, p. 69), is the one presented by Newton to Littleton Powys, from the Lilford library.² Of the fifty largest-paper copies Macomber has traced twenty-eight in all as now in existence.

Of later English editions, the collector should certainly have the English translation, in two volumes, by Andrew Motte, 'To which are added the Laws of the Moon's Motion, according to Gravity. By John Machin,' issued in 1729. It is becoming a scarce book. I also possess a beautiful copy of the edition of this book revised by W. Davis, which was issued in three volumes in 1803. This contains a life of Newton, of little worth: it gives the 'Oh, Diamond! Diamond!' story, for which there is not the slightest evidence, and says of Newton: 'He was indeed of so meek and gentle disposition . . . which will astonish those who know, for instance, of the disputes with Hooke or the dealings with Flamsteed. I do

not possess any of the American editions, the first of which appeared in 1846. In 1934 Motte's translation was reprinted in America in a volume which bears on the spine the name of Cajori, who revised the translation, but not that of Motte.

The *Principia* was translated into French by Madame la Marquise du Chastelet (usually printed as Châtelet today), the reputed mistress of Voltaire³; the work appeared in 1759 in two

² Powys is the family name of Baron Lilford; the first Baron was Thomas Powys, created 1797.

³ 'Cette liaison qui troubla sa vie, et nuisit à sa réputation, a donné lieu à plusieurs anecdotes que nous ne rapporterons point ici, les unes par respect pour la décence, les autres par égard pour la vérité. Au reste, quelle qu'ait été la nature de cette liaison, le souvenir en sera plus durable que les ouvrages de Mme du Chastelet . . . —Michaud.

handsome quartos. My copy is from the Luton library, and accordingly bears the bookplate of the Marquess of Bute. The Marquise had died in 1749, and the translation was 'revûe' by the celebrated mathematician Clairaut, some of whose researches are embodied in a commentary appended to the translation. Exactly how much of the translation is due to the learned Marquise and how much to Clairaut, who had earlier given her scientific instruction, must remain a matter of conjecture.

At the beginning of the book is a poem by Voltaire on Newton's physics, addressed to the Marquise, whom he styles '*Minerve de la France, immortelle Emilie.*' This poem brings us to another desirable book, for it first appeared in Voltaire's excellent popular account of Newton's discoveries, *Elémens de la Philosophie de Newton* (Amsterdam, 1738). The book varies in the portraits used as frontispieces: I have a copy which appears to be as issued, without portraits; and another, bearing the signature of C. Horrebow, the Danish astronomer (son of the more famous P. Horrebow), with two frontispieces facing one another—one a man in Roman dress and laurel crown, writing, with emblematical figures and clouds in the upper part of his study, the other a portrait of Voltaire. In an edition of the same date, with the imprint London (Voltaire's imprints do not mean much), a portrait of Newton (very bad) faces the portrait of Voltaire. A 1741 edition, likewise London, has the portrait of Newton only. The 1741 edition contains the famous story of the apple, whereas the editions of 1738 do not, which is the more astonishing since it appears in Voltaire's *Lettres sur les Anglais* of 1733. Of this book I have only the English version, which, under the title 'Letters concerning the English Nation,' appeared in the same year. I have likewise an English translation of Voltaire's *Elémens*, made by John Hanna, 'Teacher of the Mathematics,' which appeared in the same year as the original, 1738.

Returning to the *Principia*, the foreign editions begin with that of Amsterdam of 1714, which follows the English edition of 1713 page by page (both, of course, are in Latin), but is a fresh setting, not sheets rebound. My copy is bound in stamped vellum, a favoured continental binding at that time. Appended to the next Amsterdam edition, that of 1723, is the *Analysis per Quantitatum Series*, to which I shall refer later: my copy of this is likewise in stamped vellum. The collector must have the edition brought out at Geneva in 1739, generally called the 'Jesuits' edition'—but er-

OPTIQUE DE NEWTON,

TRADUCTION NOUVELLE,

FAITE par M*** sur la dernière Édition originale,
ornée de vingt-une Planches, & approuvée par
l'Académie royale des Sciences ;

DÉDIEE AU ROI,

Par M. BRAUZZI, Éditeur de cet Ouvrage, l'un des Quarante
de l'Académie Française; de l'Académie della Crusca; des
Académies royales de Rouen, de Metz, & d'Arras; Professeur
Embrité de l'École royale militaire, & Secrétaire-Interprète
de MONSIEUR COMTE D'ARTOIS.

TOME PREMIER.



A PARIS,

Chez LEROY, Libraire, rue Saint-Jacques,
vis à vis celle de la Parcheminerie.

M. DCC.LXXXVII.

Avec Approbation & Privilège du Roi.

FIGURE 3 - Title-page of Marat's translation of Newton's 'Opticks' into French.

roneously, for Thomas Le Seur and Francis Jacquier, to whom the excellent commentaries are due, were Minims,¹ not Jesuits. It is in three volumes, often bound as four, as is my better copy. A more accurate and amended version of this edition (*Editio altera longe accuratior & emendatior*) was printed at Geneva in 1760. The edition of Le Seur and Jacquier was long the standard one. It is amusing to note that whereas the printing place of the first edition is given as *Genevae*, for the second it is *Coloniae Allobrogum*, the older name of the town. Some pedant must have objected to Geneva. I have various later editions, such as that with the Le Seur and Jacquier commentaries printed at Glasgow at the university press in 1822, and reissued in 1833, but they do not possess special interest.

¹ The Minims were founded by St Francis of Paola in Italy in the middle of the fifteenth century and spread into France. Although their institutions are based on the rule of St Francis, they have nothing to do with that rule.

In 1728, and therefore posthumously, appeared under Newton's name a 'Treatise on the System of the World'; the authenticity has been doubted, but, it would appear, quite unjustly. It is a popular account of the third book of the *Principia*. It was translated from a Latin version which, however, appeared later (1731): according to the title-page of this version the book was *In Usus Juventutis Academicæ*, for the young men of the universities. The English version went through three editions, so apparently it was popular, especially if it be remembered how small a part science played in university courses in those days.

After the *Principia*, the most important book published by Newton is the 'Opticks: or a Treatise of the Reflexions, Refractions, Inflexions and Colours of Light. Also Two Treatises of the Species and Magnitude of Curvilinear Figures,' with a very handsome title-page in red and black. This was not published until 1704, when Newton was sixty-one, although much of it was written long before. It is generally accepted that Newton withheld publication until after Hooke's death in 1703, to avoid controversy. Whereas the *Principia* first appeared in Latin, the 'Opticks' is in English, but the two mathematical treatises announced in English on the title page are in Latin, *Enumeratio Linearum Tertii Ordinis* and *Tractatus de Quadratura Curvarum*. My best copy is bound in contemporary red morocco, with gilt edges, possibly for presentation, although it has no inscription; I have never seen another copy so bound. At that time a Latin version was essential for continental Europe, and accordingly a Latin translation by Samuel Clarke appeared in 1706, with the title *Optice*: my copy belonged to J. L. E. Dreyer, famous for his studies in the history of astronomy. Both the English and the Latin were quartos printed by Sam. Smith and Benj. Walford, Printers to the Royal Society. In the Latin edition important additions were made to the very significant 'Questions' with which the book ends: there are sixteen in the English and twenty-two in the Latin. The additional ones, which much exceed the original ones in total length, include a discussion of the nature of polarized light which appears here for the first time, and, further, astonishing speculations about light and atomic structure, one beginning 'Are not gross Bodies and Light convertible into one another and may not Bodies receive much of their activity from the particles of Light which enter into their Composition?' (I quote from the later English translation).

The second English edition, in octavo, is essential to the collector because of further additions to the 'Questions,' which now number thirty-one. There were, apparently, two issues, for some title-pages bear the date 1717, while 1718 is the commoner. The third edition, 1721, is a reprint of the second, with a few words added at the very end, and the fourth, of 1730 and so posthumous, is a reprint of the third. A copy of the fourth, which I possess, is interesting as having been given as a prize in 1742 at Trinity College, Dublin, the arms of which it bears on the cover; it was later owned by Dreyer and after that by E. F. Armstrong, who gave it to me. A second edition of the Latin *Optice* appeared in 1719, of which I possess a large-paper copy: this edition contains the thirty-one 'Questions.'

There were two French translations of the 'Opticks' in the eighteenth century, one by Pierre Coste, in 1720 (second edition 1722), and one by 'M****' which came out in 1787, and refers scathingly, in the preface, to the Coste translation. This edition was '*dédiée au Roi*': which accords ill with the subsequent work of the translator, who was J. B. Marat, the revolutionary.

A quite distinct book, sometimes confused with the 'Opticks,' is the *Lectiones Opticæ*, which is printed from notes of the lectures which Newton gave at Cambridge in 1669, when he was Lucasian professor. Although this, therefore, represents a much earlier stage of his optical work than the 'Opticks,' it did not appear until 1729, after his death. An English translation—the lecture notes were in Latin—appeared a year earlier. I have both versions, my copy of the Latin being from the library of Walter Bowman, who, judging from other volumes in my collection, bound his Newton books uniformly in fine full calf. The Latin book consists of two parts, of which only the first appears in the English translation: the only translation of the whole work of which I know is that into Russian, published in 1946, of which I possess a specially bound presentation copy inscribed to me by the translator and editor, S. I. Vavilov, whose recent death is deplored.

When we turn to Newton's specifically mathematical work we find his aversion from publication at its most marked: 'I do not love to be printed on every occasion' was more than ever his watchword. The only work published by himself is that appended to the 'Opticks,' already mentioned. The manuscript *De Analysi*, communicated by Newton to Barrow in 1669, which contains the fundamental principles of the differential and

integral calculus, was first published by William Jones, under the title *Analysis per Quantitatum Series*, in 1711. The book includes the two treatises which were appended to the 'Opticks.' There are copies on large and thick paper, of which I possess one inscribed by Sir William Jones to 'Mr. Allen.' It formerly belonged to R. A. Sampson, Astronomer Royal for Scotland. In 1736, John Colson published an English translation of a Latin manuscript *Geometria Analytica*, the Latin itself being included in Horsley's *Isaaci Newtoni Opera Quae Exstant Omnia*, 1779. As for Colson's book, it has a very good commentary and is illustrated with an amusing picture of a sportsman shooting at a bird, designed to illustrate the elementary principles of the differential calculus. My copy is a large-paper one, which appears to be unrecorded. John Stewart in 1745 produced an English translation of the *Quadratura* and the *Analysis*, with a commentary: 'the whole accommodated to the Capacities of Beginners, for whom it is chiefly designed,' a handsome work in large quarto. Mention should be made of a French translation, *La Méthode des Fluxions et des Suites Infinies par M. le Chevalier Newton*, 1740, by the perhaps unexpected hand of Buffon, the celebrated French naturalist. It has an excellent preface.

For the history of the Leibniz-Newton controversy concerning the invention of the calculus, the *Commercium Epistolicum* is an essential document. I do not possess the first edition of 1712, but have copies of the second and third editions, of 1722 and 1725, which contain additions and alterations. A critical French issue of 1856 is of interest. It would be tedious to detail, or even to list, all the books bearing on this dispute, which still engages the attention of the learned.

Mention must be made of the *Arithmetica Universalis*, which appeared in Latin in 1707, again *In Usum Juventutis Academicæ*. The academic youth, if able to understand it, must have been pretty tough, for, as H. W. Turnbull says, 'It contains a vast amount of material with a Wallis-like sweep over elementary arithmetic and algebra and penetrates far into the theory of equations.' It gives, for instance, a rule for the discovery of imaginary roots of equations which was not finally proved until 1865, by the great mathematician Sylvester. As usual, Newton was reluctant to let it be printed. David Gregory writes concerning this book: 'He (Newton) intends to goe down to Cambridge this summer and see it, and if it doe not please him to buy up the coppies. It was read by way of lectures many

years ago, and put in the Public Library according to the Statute.' William Whiston, the cantankerous divine, was responsible for seeing it through the press. There are subsequent editions of the Latin book, including a very handsome Amsterdam edition of 1761, in quarto, edited with an extensive commentary by Castillioneus¹ and additions by other authors: my copy of this is in stamped vellum. There were three editions of the English translation, which was first published in 1720.

These are the chief items in which Newton's scientific work appeared, but he spent much of his time in other fields, including chronology, theology, and chemistry. 'The Chronology of the Ancient Kingdoms Amended' appeared posthumously in 1728: here again, the manuscript was written, in this case at the request of the Princess of Wales (Caroline of Brandenburg-Ansbach), without any design to publish, and, by a breach of confidence which distressed Newton, a French version, under the title *Abrégé de Chronologie de M. le Chevalier Newton*, followed by a criticism by Fréret, was published by the Abbé Conti in Paris, 1725. This I do not possess, but on the other hand I own 'Sir Isaac Newton's Chronology Abridged by Himself, To which are Added Some Observations on the Chronology of Sir Isaac Newton. Done from the French, by a Gentleman. London 1728,' which is an English version of both Newton's writing and Fréret's criticism. This book is very scarce. Of the 'Chronology' itself my best copy is on extra-large paper, 28.2 × 22.8 cm. The problem which Newton treated here was that of fitting recorded history, including Biblical events, into the time available from the creation of the world—fixed at about 4004 B.C., due account being taken of the flood, 2348 B.C. The Temple of Solomon is carefully described, and illustrated by three plates. These matters were at the time the subject of very serious study and of wide interest. A Dublin edition appeared in the same year as the London edition (my copy was given as a prize at Trinity College, Dublin). Works dealing with Newton's chronology include a defence, published at Frankfort-on-Main in 1757, by Sir James Steuart,² in French, against the criticisms of Souciet, and a voluminous attack by Fréret,

¹ Jean-François Salvemini; he took the name of Castiglioni, Castillon, or Castillioneus from the little town of Castiglione in Tuscany, where he was born.

² Or Stewart (the name is spelt both ways and given on the title as S—t), the political economist, who afterwards took the name Denham.

published posthumously in Paris in 1758. The chief interest of these books is that they illustrate a strange aspect of Newton's character, and give a vivid picture of an aspect of the scholarship of the time.

The published theological work of Newton's is 'Observations upon the Prophecies of Daniel, and the Apocalypse of St John,' 1733. In his biography of Newton, Sir David Brewster points out that the great man had been an ardent student of the scriptures from his youth, and says: 'This ingenious work is characterised by great learning, and marked by the sagacity of its distinguished author.' It ought to be in every Newton collection and is, perhaps, the easiest item to obtain at a small price.

As regards the complete works of Newton, there is no definitive edition, and the colossal difficulties of preparing one may well mean that there never will be. In 1779-85 appeared a collected edition to which reference has already been made, with the title *Isaaci Newtoni Opera Quae Exstant Omnia*, edited by Samuel Horsley, in five volumes in quarto. It is a very handsome production, and contains the texts issued in book form and certain other valuable matter, such as, for the first time, the original text of the unfinished *Methodus Fluxionum*, and also of letters to the Royal Society concerning the reflecting telescope. It is, however, far from complete, not even giving the papers printed in the 'Philosophical Transactions' or letters given in Birch's 'History of the Royal Society,' 1756-7 (of which I possess the Marquess of Bute's copy). Nevertheless, it is a valuable and necessary publication, of which my copy is in contemporary russia, with gilt edges, in immaculate condition. There is recorded by more than one authority a 'complete edition' of Newton's works in eight volumes: this is in no sense an edition, but a collection that can be made up of the *Opuscula*, edited by Castillioneus, published in three

volumes, Lausanne and Geneva, 1744; the Le Seur and Jacquier *Principia*, 1739-42; the *Arithmetica Universalis*, edited by Castillioneus, Amsterdam 1761; and the *Optice* with the imprint Lausanne and Geneva, 1740. There is no evidence that the different publishers and editors ever issued the books with a view to making an edition of Newton's works.

There is, of course, a host of other books in any Newton collection that makes a pretence to completeness. We have works of popularization, such as Algarotti's *Dialoghi sopra La Luce, I Colori, e l'Attrazione* (with the motto *Quae legat ipsa Licoris*), 1737, which attained great popularity, and was rendered into English as 'Sir Isaac Newton's Philosophy Explain'd for the Use of the Ladies. In Six Dialogues on Light and Colours,' the translator (anonymous) being Elizabeth Carter, Dr Johnson's friend. We have attacks on Newton's scientific work, such as Rizzetti's *De Luminis Affectionibus*, 1727, and those of the cranks recorded in De Morgan's 'Budget of Paradoxes'—which reminds us of De Morgan's 'Newton: his Friend: and his Niece,' a necessary book on a delicate subject. We have the various 'Lives,' by Brewster, L. T. More, J. W. N. Sullivan, and others; the witness of contemporaries, such as Stukeley and Whiston; and modern books bearing on Newton's work at the Royal Mint, such as Dana Horton's 'Silver Pound' and Sir John Craig's 'Newton at the Mint.' The bibliographies of Gray and of Macomber, sale catalogues, the records of the Royal Society tercentenary celebrations, and various memorial volumes must be on the shelves. To list these, and the various contemporary and later eighteenth-century items which have interest for the Newtonian, might entertain the writer but would probably depress the reader. He who has acquired the volumes which have been mentioned in detail here will have gone some way to start a satisfactory Newton collection.

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Alkaloids in plants

W. O. JAMES

The part played by alkaloids in the metabolism of the comparatively few plants in which they occur, and the mechanisms by which they are formed, are questions of general as well as of purely scientific interest. Many alkaloids have an extremely powerful toxic action on animals, yet certain plant cells are unaffected by even high concentrations of them. Moreover, alkaloids do not appear to be of value to the plant. Dr James discusses these perplexing problems.

Alkaloid problems interest workers in many branches of science, and, although alkaloids are formed exclusively in plants, botanists are apt to know less about them than chemists and those concerned with the various aspects of medicine. A botanist who confesses to an interest in alkaloids is invariably asked one question—why do plants form them? It makes little difference whether the inquirer is an organic chemist to whom alkaloids are primarily pretty problems in molecular structure, a druggist or a physician concerned with their curative properties, or just a layman who likes tobacco in his pipe. Nine times out of ten, or even oftener, a teleological answer is expected. The earlier botanists took the same attitude, and attempted to provide the kind of answer desired.

The most popular solution along these lines has always been the idea of protection, and a very interesting analogy has recently been provided by the study of systemic insecticides. These substances, when introduced into the sap stream of plants, become distributed throughout them and accumulate in the young growing regions of the shoot-apices. A hundred per cent. mortality has been reported among cabbage aphids sucking the juices of *Brassica* leaves allowed to take up dilute solutions of *bis*(*bis*dimethylaminophosphonous) anhydride; the reagent had no injurious effect on the plant tissues [1]. Alkaloids frequently accumulate in tender apical tissues, and in the surface layers of leaves and older parts. Errera [2], whose school first demonstrated these distributions in numerous plants, suggested that alkaloids might serve as a protection against insects and herbivores, and the suggestion has been repeated from time to time. The facts do not, however, lend much support to this idea. Commercial growers of tobacco, tomatoes, and potatoes do not find their crops immune from insect attack, in spite of the relatively high alkaloid-content of their tops. It is a curious fact that *Nicotiana* species, which

accumulate nicotine to a considerable extent, are freely attacked by insects to which nicotine sprays might be lethal [3]. The great toxicity of alkaloids is often surprisingly specific, a fact familiar from the use of quinine to control protozoa in the human host. Conversely, alkaloids very poisonous to man may be harmless to other animals, including mammals. Even the low concentrations of *l*-hyoscyamine in belladonna render a few grams of fresh tissue toxic to both children and adults, but much larger amounts are eaten with impunity by rabbits, hares [4], many farm animals, and birds. Caterpillars of *Pieris rapae*, flea-beetles, and aphids may all ravage belladonna crops; and *Duboisia* is not immune, though its foliage accumulates the same alkaloids in a tenfold concentration [5]. The quinine alkaloids that accumulate to a quite exceptional concentration in *Cinchona* bark do not protect it from the attack of caterpillars, within whose bodies crystalline cinchonine may be deposited [6]. Nor do the alkaloids appear to be of much effect as fungicides, the inroads of *Phytophthora* upon potatoes, tomatoes, and tobacco being a familiar illustration. Moulds flourish on the overripe berries of belladonna, and its seedlings are all too easily damped-off by *Pythium*. *Cladosporium fulvum* is tolerant in culture of a variety of alkaloids investigated [7], though *Phymatotrichum omnivorum* is said to be inhibited by low concentrations of berberine and sanguinarine, and unable to infect roots containing them [8]. The angiosperm parasite dodder (*Cuscuta*) penetrates alkaloid-containing cells of *Conium* and *Delphinium* [9]. It seems clear that acting as protection to plants cannot be a general function of the alkaloids, even if it should prove to have reality in a few special instances.

Detoxication has also been proposed as a possible role for alkaloids, though with even less to be said in support. The idea is that alkaloids, themselves harmless to the plant forming them, may

represent the metabolic locking-up of materials that would otherwise be harmful. A similar role has been ascribed to the acid amides in removing excess of ammonia. Amide-formation is comparatively simple and rapid, and does sometimes seem to buffer ammonia concentrations. Pictet [6] suggested that alkaloid-formation prevented the accumulation of toxic quantities of amino acids such as proline, histidine, and tryptophan, but the suggestion remains without experimental support.

A further suggestion, more difficult to assess at present, is that alkaloids may include regulatory growth-substances among their number. Some vitamins, co-enzymes, and prosthetic groups of enzymes include nitrogenous bases in their structures, and it is possible that alkaloids are associated in some way with their formation. Nicotinic acid, related to nicotine, is, for example, an essential growth-factor in plants. It remains true, however, that the great majority of plants—probably about 90 per cent.—neither form alkaloids nor obtain them from external sources. Moreover, many of those that do normally form alkaloids may be grown as alkaloid-free scions without showing any obvious departures from the normal in their visible characteristics.

Attempts to show that alkaloids are of value to a plant's economy as reserves, in the same way as starch and some proteins, usually meet difficulties of one or both of two kinds. Alkaloids rarely accumulate in amounts comparable with those of the recognized reserve substances, and the formation of many of them appears to be irreversible during the normal life of the plant. Exceptions to both these statements exist, but evidence of the return of alkaloidal materials to metabolic circulation is limited to a few seedlings and senescent leaves, and the quantities involved are always extremely small [10]. Alkaloids rarely represent more than one or two per cent. of a plant's nitrogen, and a smaller percentage of its carbon.

The evidence for any sort of result of alkaloid formation useful to the existence of the plant is so slender that most investigators have been reconciled to labelling them as waste products, or, as Tschirch [11] picturesquely put it, as flotsam thrown up on the metabolic beach. Such a conclusion is not very inspiring, and, unlike the familiar waste-products, alkaloids are retained within the organism, usually in living cells. More important, they are structurally complex end-products of elaborate energy-absorbing sequences, instead of simple products of energy-liberating degradations such as carbon dioxide and urea.

The alkaloids appear to be worthy of something more than such summary dismissal, and it may therefore be pointed out that, even if positive support could be given to any of the suggestions summarized above, it would still not amount to explaining, in the strict sense of science, why alkaloids are formed. Protection, detoxication, regulation, or storage, if they existed, would be consequences of alkaloid-formation, not its causes, and it is the business of the experimental botanist to try to explain how alkaloids come to be in his plants, in terms of causes rather than results. Although such an answer would probably be too academic altogether to satisfy the man with a pipe, it might perhaps be acceptable to the physician.

This sort of answer cannot yet be given in the fulness of detail for any single alkaloid, but it does seem possible to state it in general terms. It does not, however, yet appear to have been put on paper. Alkaloid-formation is a metabolic act involving longer or shorter reaction-chains, which may be thought of as starting from substances normal and essential in plant metabolism in general. It is a credible convention at the present time that the biosyntheses of alkaloids start from the amino acids which are present in all plants, whether alkaloid-forming or not. An alkaloid-forming plant is one in which an additional metabolic reaction-chain has been evolved. The taxonomic distribution of alkaloids, with characteristic groups of related alkaloids confined to small groups of plant species, has long been held to uphold such a view, and the paucity of the exceptions that have been revealed by increasing knowledge has detracted nothing from it. The possession of a particular reaction-chain is heritable, and a given species always forms the same group of related alkaloids, in more or less fixed proportions and within fairly narrow limits of concentration. It has proved very difficult to modify these relations, even quantitatively, by simple experimental means. In other words, primary control of the reaction-sequence lies with the gene complex, and will be expressed through its moulding of the structural pattern of the protoplasmic proteins, and particularly of its catalytic proteins, the enzymes. Alkaloid-formation depends, like any other metabolic process, upon a protein-pattern which leads to certain chemical reactions. Variations and changes of the pattern may cause corresponding changes in the process directed, and will themselves originate from changes of the genotype due to mutation or hybridization. Examples of metabolic mutation are sometimes

quite simple. Direct control of a particular enzyme by a single gene has been recognized in man, animals, moulds, yeasts, algae, and flowering plants [12]. It is possible to regard catalysis of the formation of a specific enzyme by a specific gene as the fundamental connexion between genetics and biochemistry. The biochemical study of the mutants of the mould *Neurospora crassa* has provided well known and elegant examples among the synthetic sequences leading to amino acids.

Among the higher plants, the process most studied from this angle has been the synthesis of the anthocyanin pigments. A simple example is given by a gene affecting the flower-colours of *Primula sinensis*. The dominant allele leads to the production of a delphinidin derivative, and the corresponding recessive to the formation of pelargonidin. On the common assumption that the primary anthocyanidin is cyanidin, this is equivalent to the control of a single oxidizing reaction by the dominant, and a single reducing reaction by the recessive [13]. An example, possibly of a similar simplicity, has been examined among the alkaloids. *Nicotiana tabacum* forms nicotine as its principal alkaloid, while *Nicotiana glauca* forms the related anabasine. On crossing the two species, it was found [14] that 'anabasine' formed the principal alkaloid of the F_1 plants; in later generations a mixture of comparable amounts of the two alkaloids was present. Reason has been given to suppose that the 'anabasine' reported included a large proportion of nornicotine [15]. If this be so, it would appear that *Nicotiana glauca* possesses a gene, absent from *Nicotiana tabacum*, controlling an enzyme which effects the removal of the N-methyl group from nicotine; other evidence supports the suggestion. The replacement of nicotine by anabasine, which also occurred, involves more complex relations.

The formation of a long reaction-sequence by successive mutations, each developing a single step, seems a very lengthy and somewhat improbable occurrence. It is not necessary to suppose that alkaloid syntheses have developed solely in this hard way. Some of the simpler alkaloids could arise by very short series of chemical stages from common amino acids. Thus it is plausibly suggested that hordenine arises from tyrosine in three steps: by decarboxylation of the amino acid to tyramine, followed by two successive N-methylations to monomethyltyramine and hordenine. A single mutation, originating a tyrosine decarboxylase, might accomplish this, since a transmethylating enzyme with low specificity for the methyl

acceptor might well be part of the cell's already existing equipment. There seems to be no reason to suppose that a particular enzyme may not participate in more than one reaction-sequence. Enzymes of both the types mentioned above are known to exist in various tissues. Longer reaction sequences may also have more moderate enzymatic requirements than appear at first. Not every step of a cellular synthesis is necessarily enzyme-catalysed. It has been shown that the formation of the alkaloids lobelanine and pseudopelletierine from suitable precursors occurs *in vitro* without catalysts at acidities near neutral [16], and it is conceivable that even within the cell some steps are spontaneous.

A most interesting possibility arises from the fact that it is not necessary to suppose that every new, or apparently new, enzyme requires a new or modified gene for its formation. It is now well known that many enzymes are not constantly present in the cell, but exist only so long as some exciting factor operates. The most familiar enzymes of this kind are the adaptive enzymes, which exist only so long as a particular substance, their substrate, is formed by, or is presented to, the cell. Adaptive enzymes are best known among the lower organisms, especially the bacteria. They have been little investigated among the higher plants, and it might be supposed that they did not occur in these relatively fixed and less metabolically variable types. From at least two sources there appears to be evidence to the contrary. It has long been known that the hydrolysis of starch is catalysed in the earliest stages of barley germination by β -amylase. After a brief interval α -amylase makes its appearance, and accelerates the hydrolysis both of starch and of the long-chain dextrans formed by the β -enzyme. It has further been shown that, as carbohydrate exhaustion sets in, the α -amylase disappears. The time-curve of α -amylase activity during germination follows closely the curve of concentration of long-chain dextrans [17]. It exists only so long as dextrans capable of giving colour-reactions with iodine are present. It thus seems clear that the presence of one or more of these dextrans is able to promote α -amylase formation, though the most complex substrate, starch, does not. It is interesting to note that the ultimate product of amylase activity is maltose, but that most of the starch is degraded *in vivo* to sucrose, possibly through the competitive activity of a phosphorylase system. At the present time, any service of α -amylase activity to the organism is almost as problematical as that of

alkaloid formation. Adaptive enzymes also seem to be found in *Arum* and similar spadices, where breakdown of a large excess of starch occurs at high speed, accompanied by an oxygen-uptake about a hundred times as fast as that in adjacent tissues. The rapid degradation of starch leads to the formation of unusual amounts of oxidizable intermediates beyond the normal oxidizing capacity of the cellular equipment. Most of the plant's tissues appear to depend largely upon a metallo-enzyme as their terminal oxidase, but this enzyme is not found in the spadix. During the period of rapid respiration, an enzyme of flavo-protein type develops in relatively high concentration. The phenomenon presents an interesting parallel with the development of a similar enzyme in yeast when its metallo-enzymes are suppressed by cyanide poisoning. The substrate for the flavo-protein is probably a pyridine nucleotide (co-enzyme I or II), and it has been shown that the rate of oxidation in *Sauromatum* spadices runs parallel with the concentrations of these substances [18].

A single mutation of a gene might therefore set

in operation a whole series of new reactions, leading to complex and initially unpredictable syntheses. Any changes of this kind would occur quite irrespective of whether the ultimate products were useful or lethal to plants, or entirely without effect upon them. By such processes it is easiest to imagine that the immense wealth of chemical entities formed by plants has come into existence. The thousands of pigments, tannins, polysaccharides, glycosides, and alkaloids already identified cannot be conceived to have each an essential and specific role. Plants, even the higher plants, have not reached anything approaching a stage of ultimate adaptation, with elimination of all redundant features and processes. The plants that we know represent a midway stage of metabolic evolution, and we are witnesses of its almost endless possibilities rather than of its logical conclusion. In the sense that many features of prototypes and early forms prove to be waste, the alkaloids may be waste products; but they arise from complex syntheses, not katabolically like carbon dioxide or alcohol.

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The biology of scorpions

MAX VACHON

Scorpions are arthropods celebrated in both history and legend, and there is no lack of material for those seeking the reasons for their wide reputation for supernatural powers and their significance in painting and sculpture. Biologists, and palaeontologists too, can find much to interest them in scorpions. It is impossible to discuss here all the features which make them so fascinating; the present article is restricted to certain peculiar features of their biology and morphology, and attempts to explain some of the apparent contradictions which are found.

Scorpions and the related spiders belong to a group of arthropods that has been distinct for several hundred million years. Scorpions differ in many ways from insects, the whole head and thorax forming a single unit, the cephalothorax, covered by a shield. Behind the cephalothorax come an abdomen of seven segments and a tail with five, terminating in a further segment, the poison gland.

In front of the head there are two small pincer-like appendages pointing forwards; these are the chelicerae (figures 5, 8). There are five pairs of legs, the first pair of which, the pedipalpi, are strong and terminate in claws. The bases of these two legs form part of the mouth (figure 13). The remaining four pairs are alike, and are used for locomotion.

Behind the legs and covering the ventral part of the cephalothorax, i.e. at the start of the abdomen and behind the genital region (figure 13), there are a pair of curious appendages, the pectines or combs. These are peculiar to the scorpions, and are found in both young and old of both sexes. With the poison gland, they serve to distinguish scorpions from all other arthropods.

A rare anomaly, which has attracted much attention, consists in a doubling of the tail. Figure 1 shows an adult female with two identical tails, each perfectly formed. This division of the rear end of the body sometimes also affects a portion of the abdomen; it originates during embryonic development—a case of incomplete twinning. The anomaly was known in antiquity, for Pliny, citing Aelian, placed these double-tailed scorpions in a class by themselves.

SCORPIONS AS LIVING FOSSILS

Scorpions are one of the oldest forms of life still to be found on the surface of the earth. Only a few hundred fossilized specimens are known, but it must be remembered that we are dealing with a

land animal whose chances of fossilization may well have been slight. Examples recorded from many parts of the world show us that the scorpions have remained essentially unchanged for hundreds of millions of years. Fossil scorpions resemble the present-day *Pandinus* (figure 4) in possessing a pair of chelicerae, a pair of pedipalpi, four pairs of legs for locomotion, a poison gland, and ventral pectines. It is thus impossible wrongly to classify a fossil scorpion, and modern scorpions may well be described as 'living fossils.'

It must not be assumed, however, that the scorpions have remained completely unchanged from the earliest times. It is possible to discern differences of detail between fossil and present-day scorpions which have resulted from an evolutionary process; these have been studied by the American arachnologist A. Petrunkevitch [5, 6].

THE STABILITY OF THE SCORPIONS

During vast epochs of time, scorpions have been subjected, like other forms of life, to great geological and climatic changes. How have they been able to resist these changes, to adapt themselves to them, and to survive? I have recently published a revision of the north African scorpions [9], of which two examples (figures 2 and 3) are shown here, and in the course of this study I have put forward certain hypotheses to explain their sustained success.

North Africa has not always been a desert as it mainly is today; in the course of time it has undergone a succession of wet and dry periods. After the final rainy period of the Quaternary, a long dry period set in which transformed a region of luxuriant growth into a desert. How did the Tertiary fauna withstand this catastrophe? The present distribution of the scorpions of the Sahara is characteristic: they are few in numbers and are split up into small colonies, last relics of a past greatness. There are regions virtually devoid of



FIGURE 1—*Buthotus alticola* (Pocock), adult female from Afghanistan, with two perfect tails. Length of body 9 cm.



FIGURE 2



FIGURE 3

FIGURES 2 and 3 - Two characteristic scorpions from north Africa.

- (2) *Androctonus australis* (L) hector C. L. Koch, a lethal species from the northern borders of the Sahara. Length of body 9.5 cm.
- (3) *Orthochirus innesi* E. Simon, a species from the Saharan oases. Length of body 3 cm.



Gaillard. 7

FIGURE 4 - *Pandinus imperator*
(G. L. Koch), adult female from French
Guinea. Length of body 18-20 cm.



FIGURE 5

FIGURES 5 and 6 – *Two postures of Androctonus australis (L) hector C. L. Koch.*

(5) *At rest. Chelicerae clearly shown.*

(6) *Position when on defensive or in search of prey.*



FIGURE 6

Gaillard. 7



FIGURE 7



FIGURE 8

FIGURES 7 and 8 - *Two postures of Androctonus australis* (L) hector C. L. Koch.

(7) *Capture and anaesthesia of prey.*

(8) *The prey is consumed, held by one claw and the two chelicerae.*

Gaillard. 7



FIGURE 9 - Posture known as the 'arbre droit' (after Fabre, and from personal observations) preceding copulation in *Buthus occitanus* (Am.), a scorpion from Languedoc, France; the female is on the left.

water where scorpions, like most other animals, have completely disappeared; there remain, however, large or small regions, from mountains to oases, where conditions, though much changed, still permit life to continue. Moreover, scorpions live in the soil, under stones, or in burrows, and they can thus relatively easily find surroundings which fulfil their requirements and which are to some extent stabilized. Finally, it must not be forgotten that even large changes in the general climate are much diminished in the superficial layers of the soil. Extensive researches into micro-ecology, especially that of insects, indicate that the micro-climate in the layer beneath the surface is largely independent of the external general climate.

Scorpions have thus managed to survive in conditions of heat and drought, first because of their subterranean habitat, and secondly because there remain here and there areas where their old conditions of life still obtain. Above all, however, they have survived because of their ecological plasticity.

It is generally believed that scorpions are characteristic of dry or desert regions, but I consider this to be wrong. They are but the remains of an ancient fauna, still quite abundant, which lived under quite different conditions of temperature and humidity. If they have survived, it is because of their great adaptability—their capabilities are great, their demands few. I cannot sustain this argument here in detail, but I can mention some remarkable experiments on the feeding and respiration of scorpions. They can, for example, remain in an inert condition at freezing-point for a period of weeks, and yet return in a few hours to a normal mode of life. They can withstand, without hurt, total immersion in water for days on end, or the blocking of seven out of their eight lungs [4]. They have remarkable possibilities of haemopoiesis (i.e. making blood) and a very small respiratory coefficient. Moreover, they are sluggish creatures and thus consume little energy in moving about. More important still, they can gorge themselves with food in a few hours, or survive without feeding for many months—even for more than a year. In my opinion, scorpions are a striking example of creatures whose persistence derives not from the fact that their surroundings have remained unaltered, but from the fact that they are able to neutralize large changes in their surroundings by resorting to their subterranean habitat; in addition, their remarkable physiology enables them greatly to vary the

tempo of their existence. Largely unaffected by extremes, they are virtually independent of their surroundings; herein lies the most certain guarantee of the immortality of their race.

DETECTION AND CAPTURE OF PREY

The food of the scorpion consists of living creatures of many kinds that share its habitat—insects (both adults and larvae), spiders, millepedes, and even small rodents. The mode of capture of prey has often been observed, and descriptions by early naturalists are well known. Here I illustrate certain characteristic attitudes. At rest, or 'sleeping' (figure 5), the scorpion is motionless, with its ventral surface against the ground, the tail curved on the flat, and the legs folded. When hungry, or if a victim is detected, the attitude of the animal changes (figure 6); it moves slowly forward, supported on its hind legs, with claws open and extended and tail raised and pointing forwards. Often the scorpion will then hesitate, and the final act of capture seems almost accidental, an act of defence rather than of attack. If the prey is active, the scorpion may even withdraw for a time, but it waits patiently and finally achieves its aim. Then, especially if the victim struggles, it inserts its sting (figure 7) where best it can, often without any delay, and the prey, held in the claws, is carried towards the chelicerae. These seize it and inflict deep wounds, through which the contents of the victim's body escape and pass into the scorpion's mouth. The chelicerae play the most important part in this operation. They break down the tissues of the victim, of which there finally remains nothing but a mass of unabsorbable residues; these are sometimes got rid of by using the claws as tooth-picks.

It is not entirely clear how the scorpion first detects its prey. The eyes are too crude to be of much assistance, and in any case the scorpion is a nocturnal animal for which visual impressions can be of no great significance. Other sensitive organs must therefore be concerned, notably the sensory hairs or trichobothria found only on the pedipalpi. These hairs are present at birth, and do not alter in number or position during growth. They are of considerable importance in classification (figures 10, 12), and certainly represent very primitive characters. The trichobothria are easily recognizable by the shape of their point of insertion, which resembles the top of a well (figure 11), by their fineness, and by the thinness of the membrane which links them to the integument. They are richly supplied with nerves, and can certainly



FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 10—Claw of *Scorpio maurus* (L), a scorpion from north Africa, living in a burrow. External view, showing the sensory hairs.

FIGURE 11—Sensory hair, much enlarged, between two ordinary hairs.

FIGURE 12—Same claw as in figure 10 (internal view).

detect minute air-currents such as those caused by movements of the prey. They are, in fact, like tiny receiving-sets, pointing in all directions and spaced out along the pedipalpi, which when extended act as huge antennae.

EXTERNAL DIGESTION

The scorpion has to macerate its prey, because the mouth is able to take in liquids only. There is a powerful pharynx, which sucks the liquid contents of the victim into the large middle intestine, where it can be digested. Scorpions are not peculiar in sucking their prey, but are unusual in that digestion is partly effected outside the body by means of powerful enzymes ejected periodically during feeding; in this they resemble some other arachnids. As the scorpion feeds, from time to time it ceases to suck and liquid is regurgitated upon the victim. It appears that this liquid originates in the middle intestine, which is rich in glandular tissue, and that the scorpion actually regurgitates its digestive fluid during its meal. The study of external digestion in other arachnids, particularly spiders and pseudo-scorpions, leads to the belief that the breaking-down of the tissues of the victim is caused not only by this intestinal fluid but by secretions from specialized glands—analogueous to salivary glands—which are poured into or over the victim at the moment of regurgitation. The anatomy of the scorpion is not sufficiently well known for this analogy with other arachnids to be perfectly reliable, but it does seem that the regurgitated fluid is activated by other substances secreted from the specialized glands, and sometimes, as in certain spiders, by the poison

itself. I have recently pointed out [8] that the poison must not be considered solely in connection with the capture of prey: it is related to the feeding-process as a whole and forms but a part, albeit the best known, of the physiological complex which constitutes the external digestion. In scorpions, too, the poison has its role in this complex; it not only cuts short the victim's resistance but aids, by catalytic or other chemical action, in the digestive process itself.

REPRODUCTION AND NUTRITION OF THE EMBRYO

In scorpions the sexes are distinct, though they resemble each other in all but small details. Fertilization necessitates the coming together of the two sexes and is accompanied by curious displays. Maccary [2] and Fabre [1] have described some of these displays, the *promenades à deux* in which male and female walk 'hand-in-hand'; and the *arbre droit* in which the two animals appear to be fighting (figure 9). The conclusion of these nuptial dances I have not observed, but anatomical investigation bears out the statements of early writers; the male fertilizes the female directly in a true copulation, which is rather rare in other arachnids. In the course of this act, the male protrudes certain special organs to form a temporary penis, with which he inserts the sperm and finally places in position a vaginal plug—a kind of post-nuptial hymen [9, pp. 31-6].

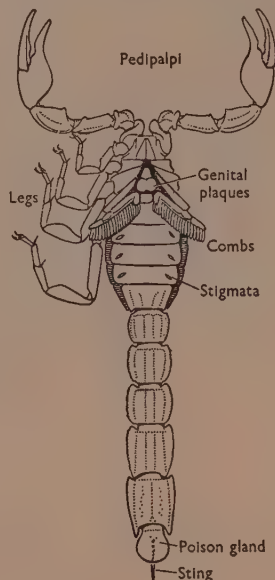
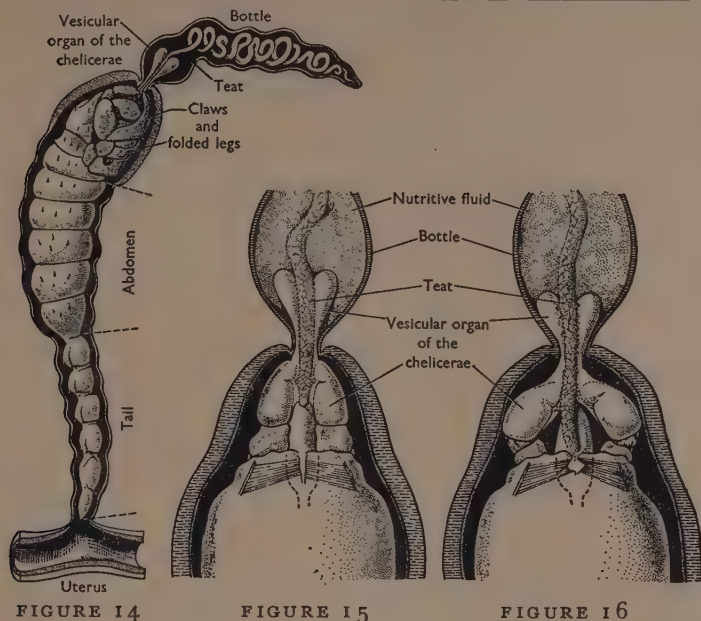


FIGURE 13—*Androctonus australis* (L), female. Ventral surface, showing the parts of the body. Total length 8 cm.



FIGURES 14-16 - *Embryos of Ischnurus ochropus* C. L. Koch, from East Africa.

- (14) Diverticulum of the uterus containing an embryo, showing the 'feeding-bottle.'
 (15 and 16) Diagrammatic representation of horizontal sections of the anterior part of the diverticulum, showing the relationship between the embryo's chelicerae and the teat; the latter can be carried to the mouth of the embryo by the chelicerae (figure 16).

The course of development of the fertilized eggs inside the mother differs according to whether the eggs are rich in yolk (as in the *Buthidae*) or are completely lacking in yolk (as in the *Scorpionidae*). In the first case, the eggs pass quickly into the oviduct and develop there, consuming the yolk with which they are filled; in the second, the fertilized egg remains in place and becomes closely commingled with the maternal tissues. At the end of its development each embryo lies in a diverticulum which possesses a tubular extension. This extension, almost an umbilical cord, is applied to the wall of the mother's intestine, from which it draws off nutrients by osmosis. The food is transformed by glandular secretions and then led through the tube to the actual mouth of the

embryo. We can almost speak of it as a bottle and teat process, since A. P. Mathew [3] has shown that at this stage the embryo scorpion has a well-developed pharynx and sucks the maternal fluid. Its chelicerae (figure 15) end in contractile vesicular organs which actually take hold of the teat and carry it to the mouth. I have described this remarkable process of embryonic nutrition elsewhere [7]. We see that although so much alike in outward appearance, there exist great internal differences between various scorpions. In some the embryo is left to feed itself on the yolk of the egg, while in others embryonic nourishment is a complex affair resulting from a process of mutual adaptation between the organs of mother and young.

CONCLUSIONS

The scorpions are members of an ancient race whose fossils go back to very early times. Their essential morphology has remained unchanged for hundreds of millions of years, and this has gained for them the name of 'living fossils.' Yet they are none the less products of evolution. The complexity of their digestive processes, carried on in part outside the body, and the mode of nutrition of the embryo in some species, requiring a close adaptation between mother and young, both bear witness to an anatomical evolution of long duration. Equally, the complex system of the sensory hairs and the elaborate nuptial dances must have evolved over immensely long periods. Ecological studies show that scorpions possess a plasticity rendering them largely unaffected by external changes. They are an example of a type which early achieved a high degree of perfection; they have subsequently continued without substantially changing, degenerating, or disappearing, but also without giving rise to new forms.

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Polyelectrolytes

A. KATCHALSKY

Non-polar polymers have been very closely investigated because of their fundamental importance in the plastics industry, but the detailed study of polymers carrying electrical charges is comparatively recent. Many natural products of this kind, such as proteins and nucleic acids, are of great biological importance, but their complexity makes them unsuitable for the study of the properties of the class as a whole. For experimental purposes, therefore, attention has been focused on synthetic products of a comparatively simple nature.

When the great initial interest aroused by the discovery of colloid phenomena had begun to abate, and this 'world of neglected dimensions,' as Ostwald called it, was in some danger of stagnating, a new impetus was given to colloid research by the development of polymer chemistry.

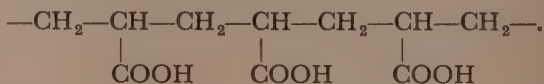
During the 1930's, Staudinger and his school [1] had realized that the units of the synthetic organic polymers are to be regarded not as colloidal aggregates of small molecules, but as extremely long molecules of colloidal dimensions which are joined by chemical valency bonds. According to this view, it is not the micellar character of the polymer which is responsible for its properties; these are due, rather, to the remarkable properties of the long-chain molecules. This fruitful idea, which underlies all modern plastics research, also profoundly influenced the development of modern views on the nature of biological colloids and the organization of cells and tissues.

With the rapid development of the plastics industry, the attention of polymer chemists was attracted mainly to the non-polar polymers which are insoluble in water and are of low chemical reactivity. Interest in water-soluble polymers, related to the biocolloids, has begun to grow only during the past five or six years. Although the industrial possibilities of these polymers are just beginning to be explored, their remarkable behaviour, which will be described below, is so interesting from a theoretical viewpoint that they deserve to be much better known.

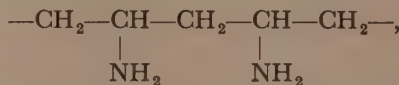
Of the biocolloids, the polymers which carry electrical charges are especially important. To this group belong the proteins, which carry both positive and negative charges; the protamines, which are predominantly positive; a wealth of such negative long-chain acids as the nucleic, pectic, and alginic acids; and numerous polyacids of bacterial origin. All these long-chain molecules, which combine the behaviour of polymers and

electrolytes, have been termed polymeric-electrolytes or polyelectrolytes.

This article is concerned mainly with the synthetic polyelectrolytes, which have a comparatively simple structure consisting of one or two repeating units carrying ionizable groups. The polyacrylic acids, already investigated by Staudinger and his co-workers, are typical synthetic polyelectrolytes and have the formula



Others are the polyamines of the polyvinylamine type,



and the ampholytic co-polymers composed of both acidic and basic monomers.

Although these simple synthetics lack the versatility (due to changeable structure) which endows the biocolloids with a wealth of physical, chemical, and biological properties, their simplicity is an advantage to the investigator. It renders their behaviour more amenable to theoretical investigation, and may provide the scientist with an Ariadne's thread, guiding him to the centre of the problem of biocolloid behaviour.

OSMOTIC PHENOMENA

The characteristic behaviour of polyelectrolytes is most fully manifested in aqueous solutions. If an aqueous solution of a polymeric acid or base is neutralized to a certain degree by an alkali or by a mineral acid, respectively, the resulting solution will differ markedly from solutions of ordinary electrolytes or polymers in osmotic and viscometric behaviour, and in interactions with electrolytes.

First, let us consider the direct effects of the electrostatic field of polyelectrolytes. It is evident, *a priori*, that ionized groups, accumulated on a single molecular chain in extremely large numbers, which may total more than ten thousand, will produce a powerful electrostatic field around the polymer molecule. This field will profoundly influence other electrical charges in the medium. The small counter (i.e. oppositely charged) ions—especially, for example, the sodium ions surrounding an ionized polyacid—will be strongly attracted to the charged polymer molecules, and their free movement in solution will be greatly restricted. This restriction will diminish the osmotic contribution of the ions; hence the osmotic pressures of polyelectrolyte solutions will be many times smaller than those of ideal solutions. Figure 1 demonstrates the experimental verification of this conclusion. We see that deviation from the ideal increases with the degree of ionization until, at high degrees of ionization, the osmotic pressure may be only about one-fifth of the ideal.

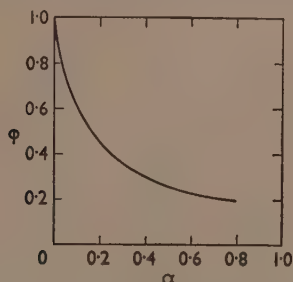


FIGURE 1—Osmotic activity of polyacrylic acid neutralized to various degrees (α) by sodium hydroxide. ϕ is the ratio of the actual osmotic pressure to the ideal. (From KERN, W., Z. phys. Chem., A, 181, 249, 1938.)

Measurements of osmotic pressure are paralleled by determinations of activity—the equivalent of concentration in real solutions. The activity of the counter ions diminishes in the presence of ionized polyelectrolytes. New measurements of activity coefficients [2] of the counter ions in polyelectrolyte solutions indicate that their activity decreases as ionization increases (figure 2). However, as neutral salt is added this polyelectrolyte effect is diminished; at sufficiently high concentration of salt, the activity of the counter ions approaches that of the salt in polyelectrolyte-free solutions, and the polyelectrolyte effect disappears. This is due to the fact that the salt ions cluster around the polyelectrolyte molecules and screen off the electrostatic field.

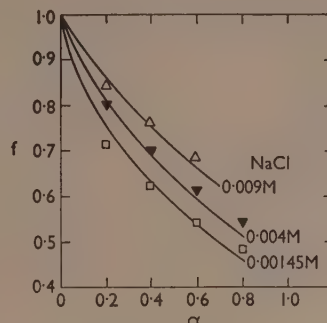


FIGURE 2—Activity of sodium chloride in aqueous solutions of ionized polymethacrylic acid. The concentration of the polymeric acid is 0.05 M throughout. The concentrations of sodium chloride are Δ 0.009 M, ∇ 0.004 M, and \square 0.00145 M; α is the degree of ionization of the polymethacrylic acid, and f is the ratio of the activity of the salt in the presence of polyelectrolyte to that in polyelectrolyte-free solution. (From the measurements of O. Kedem.)

POLYELECTROLYTE INTERACTION

According to calculations made in the author's laboratory, the energy of attraction exercised by a fully ionized polyacrylic acid on a univalent ion is 2.5 Kcal/mol-ion—almost four times the thermal energy of the ions. Since the attraction increases rapidly with the valency of the counter ions, it is not surprising that there are remarkable interactions between ionized polymers and multivalent ions.

These reactions have recently been applied, very promisingly, to practical problems of agriculture. As theory predicted, it was found that charged polyacrylic acid interacts strongly with soil particles, causing them to aggregate into larger clumps. This clumping often improves the texture of heavy soils, and increases the fertility of poorly aerated and relatively impermeable soils. Such use of the soluble salts of polyacrylic and polymethacrylic acids not only heralds new trends in agriculture, but marks the first practical application of polyelectrolytes.

When two synthetic polyelectrolyte molecules of opposite sign encounter each other, the interaction is even stronger. This type of interaction is easily carried out in the test-tube, and results in mutual precipitation. This kind of interaction, furthermore, is of outstanding importance in the organization of biological structure: typical examples are the interaction of proteins in the cytoplasm, the interaction of hyaluronic and other sugar acids with collagen in connective tissue, and the interaction of protamines and histones with nucleic acids in the chromosomes. It had been

suspected for some time that the acidic-basic polyelectrolyte interaction is also one of the most primitive and fundamental forms of biological defence against intruding micro-organisms. This was verified when Bloom, Cromartie, and co-workers [3] found that the anthrax bacillus excretes polyglutamic acid, a typical negative polyelectrolyte, which is counteracted *in vivo* by the 'tissue-factor' excreted by the leucocytes. The tissue-factor is a positive polyelectrolyte closely related, apparently, to synthetic polylysine [4]. This discovery suggests a new approach to chemotherapy based not on antimetabolites but on polyelectrolyte interactions.

Moreover, basic polyelectrolytes react directly with cell surfaces, since most cell surfaces are negatively charged. When polylysine is added to suspensions of *Escherichia coli* and *Micrococcus aureus* in concentrations as low as $10 \mu\text{g/ml}^1$ the bacteria are deposited. Measurements recently made in the author's laboratory [5] showed that almost every molecule of the basic polyelectrolyte has attached itself to the bacterial surface; the electrostatic potential of the bacterial cell is diminished, its stability in solution is reduced, and aggregation and deposition result. A typical experimental run for the attachment of polylysine to a bacterial surface is given in figure 3.

The interesting chemotherapeutic implications of these phenomena are now being investigated.

MOLECULAR SHAPE

Having seen the direct effects of the electrostatic field on the environment of polyelectrolyte molecules, we may turn to the effect of electrostatic factors on the specifically polymeric characteristics of the molecules.

Conventionally, the first step in investigating a polymer is to measure the viscosity of its solution. The ratio of specific viscosity² to polymer-concentration gives information about the molecular shape and, indirectly, about the molecular weight of the polymer. Viscometric measurements of polyelectrolytes show that the specific viscosity changes markedly with the degree of ionization. In terms of polymer-chemistry concepts, the mole-

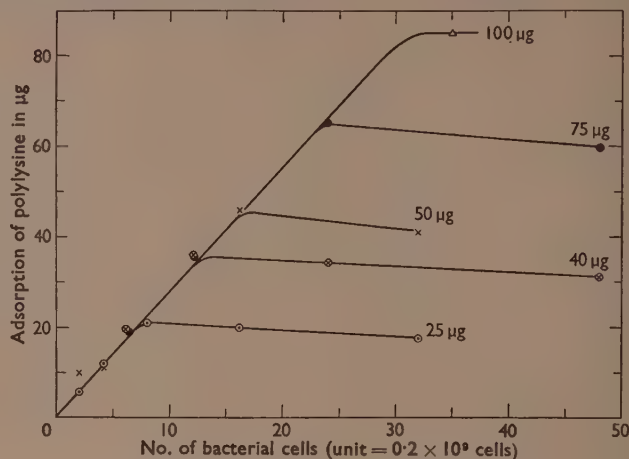


FIGURE 3—Adsorption of polylysine on *E. coli*. To solutions of polylysine containing respectively $25 \mu\text{g/ml}$ (\circ), $40 \mu\text{g/ml}$ (\odot), $50 \mu\text{g/ml}$ (\times), $75 \mu\text{g/ml}$ (\bullet), and $100 \mu\text{g/ml}$ (Δ) polylysine, different amounts of bacteria were added. The adsorption proceeds first linearly, each bacterium becoming fully covered with polylysine. After practically all the polybase is adsorbed the curves flatten out, as no further adsorption occurs. (From the measurements of L. Bichovsky-Slomnitsky. Private communication.)

cular shape is changed by the electrostatic field. Figure 4 shows a typical set of viscometric curves [6] for polymethacrylic acid in aqueous solution at different degrees of ionization. The curves for six polymers of different molecular weights show a very steep increase of specific viscosity with increasing ionization, until viscosity reaches an upper limit at about 30 per cent. ionization. Since viscosity increases with the length of the molecule, the curves may be interpreted as indicating that the molecules are increasingly stretched by the increasing strength of the electrostatic field until they reach their limit of length.

Quantitatively, if specific viscosities are plotted against molecular weight at a constant and very low degree of ionization, it can be seen that the viscosity increases with the square root of the molecular weight. According to theory, at such low ionization the molecular chains are so tightly coiled as to be almost spherical in shape. If viscosity is plotted against molecular weight at about 10–20 per cent. ionization, it is found that, in this range, specific viscosity increases linearly with the molecular weight. Theoretically, this second relationship of viscosity to molecular weight indicates that the molecules are now behaving as randomly kinked or flexing, fully rinsed molecular coils. Thus the increase of ionization from 0 to 15 or 20 per cent. is sufficient to open up the molecular coils so that they become freely flexible.

¹ $1 \mu\text{g}$ is 10^{-6} gram.

² If the viscosity of the solvent is η_0 and the viscosity of the polymer solution is η , then the specific viscosity is $(\eta - \eta_0)/\eta_0$.

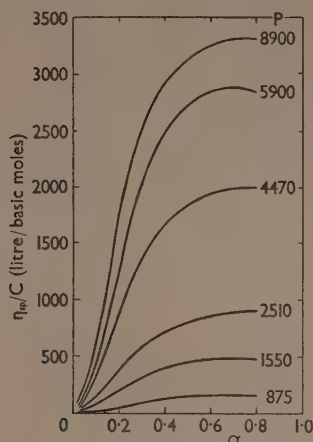


FIGURE 4 — Ratio of specific viscosity (η_{sp}) to concentration (C) plotted against degree of ionization (α) for six polymethacrylic acids of different degrees of polymerization (P). The degrees of polymerization, or numbers of simple molecules per macromolecule, are 875, 1550, 2510, 4470, 5900, and 8900 respectively. (The molecular weight of the monomer is 86; hence the molecular weight of the polymer is $P \times 86$.) The concentration of the polymeric acid is 0.01 monomolar. (From KATCHALSKY, A., *J. Polym. Sci.*, 7, 393, 1951.)

Finally, when viscosities are plotted against molecular weight in the range of high ionization, the viscosity is found to increase with the square of the molecular weight. This is due theoretically to the full extension of the molecules, which now resemble thin filamentous rods.

We must conclude, therefore, that the electrostatic field not only acts on external ions but greatly influences the shape of the molecules, stretching the initially coiled molecules to fully extended filaments.

In non-polar polymolecules the only factor determining shape is the thermal, so-called Brownian, movement. The thermal impacts of the surrounding medium cause the molecular segments to rotate around the chemical bonds, and the molecule assumes all possible forms which give it, on the average, the shape of a random coil. In the shaping of polyelectrolyte molecules, both thermal movement and electrostatic repulsion are involved. Thus the shape actually assumed results from the equilibrium between the thermal coiling tendency on the one hand, and the repulsion between charges of equal sign on the other. At low degrees of ionization, the electrostatic forces are too weak to overcome the thermal coiling, but at sufficiently high ionization the electrostatic field stretches the molecules to almost their full length. Furthermore, this shaping process is fully reversible: if the charges on sodium polyacrylate are neutralized by the addition of mineral acid, for

example, the molecules will curl up, returning to their original coil-like shape.

MECHANO-CHEMISTRY

These phenomena, in which ionization results in expansions and contractions of the molecule, are highly interesting from a general standpoint, since here we have a possible model for studying the direct transformation of chemical energy into mechanical energy on the molecular level. The next step, then, was to see whether these molecular movements could be multiplied so as to be observable on a macroscopic scale. Actually, nature provides just such devices, since the muscles as well as other motile parts of living creatures expand and contract as a result of chemical transformation. It was of interest to see whether synthetic polyelectrolyte systems would expand and contract on a macroscopic scale as they did in solution. The systems most likely to respond in this way are the cross-linked polyelectrolyte gels.

A polymer gel is a molecular network imbued with liquid. The network junctions are capable of transmitting mechanical effects through the gel, thereby making it a solid structure. It is thus reasonable to assume that in the polyelectrolyte gels the mechanical effects of ionization and deionization will be transmitted through the network structure and will result in an over-all expansion and contraction.

Spurred on by this assumption, workers in several laboratories simultaneously undertook to prepare synthetic polyacid gels. It was found that the gels did indeed expand on addition of alkali and contract on addition of mineral acid. By heating polyacrylic acid with multivalent alcohols to get a certain degree of esterification, W. Kuhn [7] obtained cross-linked acid gels. Polyacid gels were obtained in the writer's laboratory by copolymerizing methacrylic acid with cross-linking agents such as divinyl benzene [8]. It was found that polyphosphate gels, which we obtained by phosphorylating cross-linked polyvinyl alcohol, could be expanded to thrice their length by alkali, and fully contracted again by mineral acid [9]. Indeed, according to some authors the operation of these gels bears a resemblance to that of muscle systems [10].

If a weight is attached to a thread made from one of such gels, the contraction and expansion of the thread will lift and lower the weight, thus performing actual mechanical work. The gel transforms part of the energy released by the

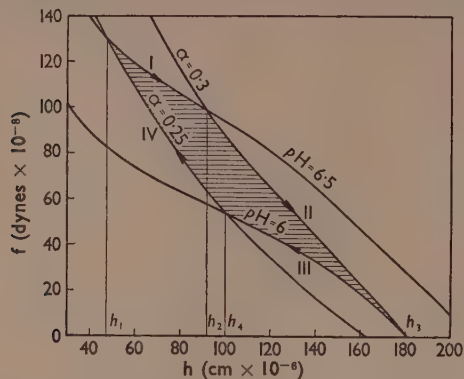


FIGURE 5 - Mechano-chemical cycle of parallel polymethacrylic acid molecules of degree of polymerization 10,000. The cycle operates at constant temperature between ionization degrees (α) from 0.25 to 0.3 and at pH 6 and 6.5. f is the force per molecule in dynes and h is the length of the molecule (its end-to-end distance). The shaded area gives the mechanical work obtained in the cycle by reason of the difference in chemical potential at the two pH's. (From KATCHALSKY, A., *J. Polym. Sci.*, 7, 393, 1951.)

neutralization process into mechanical energy, and thus operates as a very simple mechano-chemical engine.

Although this transformation can be fully reversible in the thermodynamic sense, such primitive mechano-chemical systems as have been obtained in this way are able to transform only small amounts of chemical energy into available work, owing to the limited extensibility of the molecules.

Figure 5 shows a simple mechano-chemical cycle for an anisotropic polyacid gel; it is a compression cycle and somewhat resembles the well known cycle of Carnot [6]. The mechano-chemical cycle, however, is isothermal; its source of energy lies in the difference in degree of ionization, whereas the Carnot cycle operates on a temperature gradient.

That the performance of the gel systems is restricted is due in part to the fact that all the present models are isotropic. Theoretical analysis shows that anisotropic gels, in which the molecules lie parallel, contracting and expanding along one axis without changes in volume, should have greater mechano-chemical possibilities. Indeed, from this standpoint, the beautiful anisotropy of the fibres in muscle demonstrates the efficiency of the structure of living tissue.

This system, peculiar to polyelectrolytes, is only one of the ways in which chemical energy may be transformed into mechanical energy in macromolecular structures. During the past few years other polymeric reactions have been investigated, and it has slowly become evident that not only electrostatic repulsion, but van der Waals attraction, hydrogen bonds, and crystallization tendencies may be used as potential sources of mechano-chemical transformations [11].

From these investigations a general science of mechano-chemistry is developing, a science to which polyelectrolyte research has made a contribution.

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The Szilard-Chalmers effect

A. G. MADDOCK

In 1934 L. Szilard and T. A. Chalmers described a chemical technique for the separation of radioactive isotopes resulting from neutron-bombardment of the inactive element. In effect, the element to be transmuted into its radioactive isotope was chemically combined in such a way that the isotope resulting from the impact of neutrons could not be recaptured to form the original compound. The classic example was the liberation of free radioactive iodine, finally obtained as silver iodide, by bombarding ethyl iodide with neutrons.

Direct chemical effects following nuclear transformations can arise from three causes:

(i) The emission of either particles or photons leads to a recoil of the disintegrating nucleus, momentum being conserved. The mechanical effects of this recoil, following the emission of heavy particles, were observed quite soon after the discovery of radioactivity [1]. In the case of alpha-emission the recoil is especially large, and may manifest itself as an apparent volatility of the active material; the energy of individual recoils is sufficiently great for the recoiling atom to carry away several of the surrounding unsplit radioactive atoms [2]. The physical separation of the parent and daughter brought about by the recoil, has, when the source is suitably distributed, been employed in the separation of successive members of the naturally radioactive series [3].

The recoil-energy following photon-emission is generally very much less than that after particle-emission. Its value is given by

$$E^2/2Mc^2 = 536E^2/M,$$

where E is the photon energy expressed in millions of electron volts and M is the mass of the recoiling atom in atomic mass units; the recoil-energy is obtained in electron volts. However, the photon-energies involved are often so large, particularly following neutron-capture, that the recoil-energy is large compared with chemical binding-energies. Until recent years, the chemical effects of radiative thermal-neutron capture, the Szilard-Chalmers effect [4], were ascribed exclusively to this mechanical recoil, although no direct observation of the recoil had been made. In 1951, L. B. Magnusson succeeded in effecting a small direct physical separation of the capture-product when irradiating a very thin gold target with thermal neutrons [5]. The recoiling atom may attain a translational energy of several electron volts, corresponding to the mean energy at a temperature of some tens of thousands of degrees.

(ii) Nuclear changes often result in the ionization of the disintegrating atom, thus providing a second mechanism for effecting chemical changes. If the disintegrating nucleus emits charged particles, ionization may be produced by interaction between the outgoing particle and the orbital electrons of the disintegrating atom. The probability of ionization in this manner is fairly high for heavy charged particles, such as alpha-particles. The emission of photons will generally occur without much likelihood of ionization unless internal conversion takes place. In these circumstances there is direct interaction between the nuclear forces and the orbital electrons, and ionization results without the intermediary of the photon. The electron is ejected with kinetic energy equal to that of the alternative photon, minus the initial binding-energy of the electron.

Internal conversion is favoured by a low disintegration-energy, large differences in angular momentum between the parent- and daughter-nuclei, and large atomic number. The initial ionization following internal conversion is usually in the low-lying K or L shells of the atom, but the vacancy is quickly filled with the creation of more numerous vacancies in the valence shells by Auger multiplication [6]; this further ionization will lead to decomposition either immediately or when electrical neutralization takes place. The chemical decompositions initiated by transformations between nuclear isomers are generally due to this effect. Internal conversion also leads to a greater mechanical recoil than the alternative photon-emission, because of the finite rest-mass of the electron. If the disintegration energy is E and the orbital binding-energy of the ejected electron is e , the recoil-energy is given by $(E - e)m/M$, where m is the mass of the electron and M is the mass of the recoiling atom. Nevertheless, in one case at least, namely the decomposition of tellurium diethyl owing to the disintegration of Te^{127*} , decomposition must be entirely due to ionization,

since the enhanced recoil is still small compared with bond-energies [7].

(iii) Nuclear changes must generally be accompanied by some excitation of the orbital electrons, and this in turn may produce chemical changes. When the daughter-nucleus differs from the parent in atomic number, it is likely that the energy released in the rearrangements of the orbital electrons will produce excitation, if not ionization. When only the mass-number is changed—for example, in the case of radiative-neutron capture—the energy-change will be very much smaller, and is insufficient even to break chemical bonds.

All these sources of chemical reaction may play a part in the changes following a nuclear reaction.

RADIATIVE-NEUTRON CAPTURE

Radiative-neutron capture occurs with neutrons at all energies. However, the cross-sections for the capture of neutrons above 100 keV are generally quite small, and most of the data on the Szilard-Chalmers effect refer to the capture of resonance or thermal neutrons. It is difficult to separate the effects in these two regions experimentally, and most of the data have been obtained by using an arbitrary mixture of capture by the two processes. Theoretically, some distinction between the resonance- and thermal-capture can be anticipated. The primary event of thermal-neutron capture cannot produce any appreciable recoil, nor should any other circumstance lead to chemical change in the molecule containing the activated nucleus. On the other hand, upon resonance-capture, particularly in a high-lying resonance-band situated, for example, at a few hundred electron volts, the primary event may produce a sufficiently energetic recoil to rupture chemical bonds. The spectra following resonance and thermal capture may differ.

In many cases the molecules survive the primary event, and decomposition ensues solely as a result of the subsequent photon-emission. The compound nucleus formed by neutron-capture is highly excited, the energy of excitation corresponding to the binding-energy of the neutron in the nucleus. This excess energy is soon lost by the successive radiation of photons, until the ground-state is reached. The spectrum of this photon-radiation, and the lifetimes of the initial and intermediate excited states, depend on their energies and angular momenta. The same factors determine internal conversion of radiations.

It is only within recent years that any determined attack on the investigation of the spectrum

of the capture radiation has proved possible [8], and the unequivocal detection of internal conversion of this radiation in some instances is also a recent achievement [9]. The energy of excitation is generally more than 5 MeV. The statistical theory of nuclear energy-levels suggests that the loss of this energy will probably involve the successive emission of three or four photons. Two or more paths of disintegration may be followed. The experimental results so far reported reveal that the loss of the whole of the energy of excitation in a single quantum is an event of much more frequent occurrence for some compound nuclei than had been supposed, but the average disintegration path involves the emission of at least two energetic photons [10]. There is greater variation between the forms of the spectra of the capture-radiation for different elements than was expected. These irregularities are no doubt associated with the incidence of the completion of nuclear shells. Unfortunately, the complete spectrum, together with the probabilities of emission of photons of each quantum-energy, has not yet been established for any isotope of any element. Most of the existing data refer to experiments conducted with the naturally occurring isotopic mixture, thereby introducing the additional uncertainty of correlating the photon-energies with their respective capture-processes.

THE RECOIL PROCESS

Although the emission of a photon of known energy uniquely determines the recoil suffered by the radiating atom, the spectrum and emission probabilities alone do not completely define the probable energy-distribution of the resultant recoil. In most cases, the radiating nucleus suffers two or more successive recoils, and the angular distribution and mode of combination of the recoil-momenta must be known. The only observations on the former confirm the usual assumption of independent isotropic distribution. The appropriate combination of recoil-momenta introduces chemical considerations. If successive recoils occur so fast that the effect of one recoil cannot be dissipated by the molecule before the next takes place, it is justifiable to assume vectorial combination, equivalent to coincident recoils. At the opposite extreme, the half-life of the excited states might be long enough for each recoil to be considered as a separate event.

The recoil experienced by the radiating nucleus is quickly communicated to the atom as a whole by electrostatic interaction. When the atom is

combined in a molecule, the recoil-energy becomes distributed between the translational, vibrational, and rotational degrees of freedom of the molecule. The damping-time for the dissipation of the recoil-energy communicated to an isolated molecule will therefore be that of the bond-vibrations. It can hardly be less than 10^{-8} sec, and, although few data are available regarding the lifetimes of the excited states, it can be anticipated that such lifetimes will generally be much shorter. However, low quantum-energy and large change in angular momentum could lead to longer lifetimes. Generally, the vectorial combination of randomly distributed recoils appears the most justifiable method of calculating the resultant recoil.

Not all the resultant recoil-energy becomes available for bond-rupture. It can be shown that, for the free centro-symmetrical molecule, the fraction of the recoil-energy leading to vibrational excitation is given by $m/(M + m)$, where M is the mass of the recoiling atom and m is the mass of the attached atoms [11]. Although insufficient data are available for the exact calculation of the probability-distribution of the resultant recoil-energy, a calculation made on assumptions most favourable to the minimum recoil indicates that less than 5 per cent. of the activated molecules receive insufficient energy to break a single chemical bond. However, when the activated atom is bound in the molecule by two or more bonds, there will be a substantial probability of the formation of products preserving one or more of the original bonds. The study of the distribution of the products in such cases may provide an experimental method of investigation of the distribution of the recoil-energy [12].

The spectra of the radiation emitted after resonance- and thermal-neutron capture will generally be different, so that the two processes may lead to different recoil-distributions, as will capture in different isotopes of the same element. In so far as the chemical effects depend on the magnitude of the recoil, differences in chemical behaviour will be observed.

INTERNAL CONVERSION

Photon-emission does not lead to ionization of the disintegrating atom, nor is the ensuing recoil so great that ionization by collision can occur. Nevertheless, the formation of charged radioactive atoms of bromine during the irradiation of methyl bromide with thermal neutrons has been observed [13]. They probably arise from the internal

conversion of soft quanta in the capture-radiation. The part played by these ions in the Szilard-Chalmers process has not yet been explored. Differences in internal conversion in the spectra of the capture-radiation could also give rise to differences in the chemical effects following the activation of two isotopes of an element in the same compound. It is noteworthy that the internal conversion mechanism, unlike the recoil mechanism, is essentially an oxidation. It may therefore be responsible in the relatively few instances in which neutron-capture brings about oxidation—for example, the formation of perhenate following the irradiation of tervalent rhenium chloride [14]. In condensed systems, when stabilization of the positive ion by solvation can occur, the positive ion may persist for a sufficient time to participate in a chemical reaction. Positively charged halogen ions formed in this way could play an important part in the chemical reactions following the neutron-irradiation of the alkyl halides.

RETARDATION OF THE RECOILING ATOM

Since neutron-capture must nearly always rupture at least one of the bonds in which the excited atom participates, it is perhaps surprising that a measurable proportion—the retention fraction—of the active atoms is usually found after the irradiation combined as molecules of the original compound. Most of these active molecules have re-formed during the slowing-down process.

While the mean energy transferred at each collision is large compared with bond energies, the loss of energy by the recoiling atom takes place by approximately elastic collisions with the exposed atoms on the surface of the surrounding molecules in the system. Its course is determined by the masses and concentrations of these atoms. At lower energies, in the epithermal region, inelastic collisions with the surrounding molecules are probable. Finally, the atom may reach thermal equilibrium with its surroundings. After any collision, the atom may react with the surrounding molecules or with the radicals or other products formed in the preceding collisions. However, collisions between a fast or epithermal atom and an inactive molecule can lead to reaction only if the atom and the radical formed in the collision are left with insufficient energy to escape from the vicinity of the collision. The critical energy will depend on the scattering properties of the surrounding molecules, the cage formed in the liquid phase being very much stronger than in a gaseous

material. The frequency of such reactions will therefore depend on the mean energy lost by the recoiling atom in each collision, which is determined by the mass-ratios of the recoiling atoms to the others in the irradiated system, and on the scattering properties of the system.

Sometimes the chemical behaviour of the thermal atom is known, e.g. from photochemical studies. In any case, it is possible to distinguish between reactions occurring in the thermal and in the epithermal or fast regions by conducting irradiations at different temperatures. The population of the epithermal and fast-energy domains is predominantly determined by the rate of generation of recoiling atoms, and by the slowing-down characteristics of the irradiated substance, so that the reactions of recoiling atoms in these energy-regions are hardly influenced by the temperature of the irradiated substance. Such reactions are justifiably called hot-atom reactions. The thermal reactions are accelerated in the usual way by increase of temperature, and since the distribution of the active atoms among the products is determined by the rates of the competitive reactions to which the atoms are susceptible, the yields of the thermal products are increased by rise in the temperature of irradiation.

Among the reactions of the recoiling atoms will be the re-formation of the original molecules. If the thermally equilibrated atoms, or one of their reaction-products, can exchange with the inactive molecules, then the retention will either be complete, or will increase with the time elapsing between the end of the irradiation and the analysis of the system. Alternatively, exchange may take place by a hot-atom reaction, in which case the retention will be independent of temperature.

The most informative evidence about these processes could be obtained in experiments with gases, particularly those whose molecules hold the activated atom by a single chemical bond, but as yet very few investigations of this kind have been made. The retentions reported in the few quantitative studies that have been made are all very small. A low retention in the gaseous phase is to be expected, since the colliding atom is unlikely to remain in the vicinity of the radical it creates.

Much greater retentions are found in liquids, and a substantial proportion of the published quantitative data refers to liquid systems, especially to those containing organic halides. It is on the basis of the earliest of these results that W. F. Libby elaborated the analysis of the slowing-down process which has been summarized above [15].

EFFECTS IN THE ORGANIC HALIDES

The discovery of the Szilard-Chalmers effect arose from an irradiation of ethyl iodide. It was observed that a substantial proportion of the radioactive iodine could be separated as iodide ion. It was found later, using methyl iodide, that the residual activity in the organic phase was largely present as methyl iodide, but that an appreciable amount of radioactive methylene iodide had been formed [16]. The elastic impact collision picture of the slowing-down process adequately accounts for the proportions of these products. Collisions with other iodine atoms are more likely to reduce the energy of the recoiling atom to a value permitting its combination with the radical created than are collisions with the more numerous but much lighter hydrogen atoms.

Similar experiments with propyl and isopropyl bromides have provided evidence that the radioactive organic halide is all re-formed during the slowing-down process, and that considerable excitation of the organic radical can occur. The activity retained after the irradiation of either of these bromides appears as propyl and isopropyl bromides in approximately the same ratio. In this instance, it would appear that the radical produced by the collision acquires sufficient energy for isomerization to become likely, although insufficient to enable it to escape from the cage associating it with the active bromine atom [17].

A rather more ambitious investigation of the suitability of the elastic impact collision theory of the slowing-down process has been carried out by Dodson and colleagues at the Brookhaven laboratories [18]. The distribution of activity as a function of the composition of the irradiated system was studied in a series of mixtures of carbon tetrachloride with silicon tetrachloride, benzene, and cyclohexane. The retention as carbon tetrachloride, the yield of organic chloride, and the inorganic chloride were separately determined. It was found that the retention as carbon tetrachloride was very rapidly reduced by the addition of small quantities of the hydrocarbons, but subsequently decreased much more slowly as the molar fraction of hydrocarbon was increased. The yield of the chlorine-substituted hydrocarbon, on the other hand, rose quickly to a value which became independent of the molar fraction of the hydrocarbon. These results are compatible with the above theory of the slowing-down process only if it is accepted that the hydrogen-replacement reaction takes place in an energy-domain lying

above that in which chlorine-replacement in carbon tetrachloride is feasible.

Several other observations are difficult to reconcile with the simple elastic impact collision theory. It has been found that, in irradiations of solutions of iodine or ethyl iodide in hexane and other hydrocarbons, very considerable yields of the iodine-substituted products can be obtained. Indeed, the procedure has been suggested for preparative applications and has been termed radio-synthesis. Now an iodine atom can transfer only about 3 per cent. of its energy to a hydrogen atom in a head-on collision; therefore, if it succeeds in breaking a carbon-hydrogen bond in this way, it must be left with very considerable energy—sufficient, one would suppose, to escape from the vicinity of the radical produced, so that iodine-substitution should be a rather infrequent event [19]. Further, experiments with compounds such as CCl_3Br yield an appreciable fraction of the active bromine in compounds of higher molecular weight than CCl_2Br_2 [19]. It is therefore advisable to inquire whether the results can be better interpreted in terms of other ideas. Dodson has pointed out that one can relinquish the elastic impact collision approach, and explain the concentration-retention dependence found in his experiments in terms of competing chemical reactions in the epithermal region. The appearance of complex products, which seem to be revealed by careful investigation in most organic systems, may arise from the interaction of two or more radicals in regions of high radical-density.

RECOIL-REACTIONS IN THE SOLID STATE

Some of the most interesting and unexpected phenomena are those which accompany the irradiation of solid substances. Many can be illustrated by reference to experiments with permanganates and chromates. These oxy-anions are broken by the recoil, and the radioactive manganese or chromium is subsequently found to be distributed between the original anion and a derivative of a lower valency state of the element. After solution of the irradiated crystals, the separable manganese can be extracted on a manganese dioxide carrier, and the chromium as the hydrated chromic ion. The recoiling atom or radical in the solid must ultimately find accommodation in some interstitial position, or other lattice defect, where it will become comparatively immobile. The chemical identity of this atom, radical, or ion, is generally unknown. No direct methods of identification are at present available: it is possible

merely to examine the distribution of activity after dissolution of the irradiated crystals. There is, however, evidence supporting the hypothesis that ions or radicals unknown in solution may be frozen into the lattice after recoil.

The existence of such unusual species can be inferred from Libby's [20] experiments with potassium permanganate. The retention was shown to be a function of the pH of the solution in which the irradiated crystals were dissolved. The lattice-stabilized entity containing the radioactive manganese reacts with the water in such a manner that the proportion of permanganate ions re-formed depends on the pH . Libby has suggested that the reactive ion is a derivative of septavalent manganese containing less oxygen than the permanganate ion: for example, MnO_3^+ or MnO_2^{+++} . Upon solution, this ion may either be reduced to quadrivalent manganese dioxide by the water, or combine with the hydroxyl ions to re-form permanganate ions. The hypothesis provides a qualitative explanation of the increase in retention observed upon dissolution in solutions of increasing pH , but the quantitative analysis of the data is difficult to reconcile with this mechanism [21].

Naturally, the retention is often high in solid systems. It can be attributed to six causes. The first of them, the inefficiency of the nuclear event in producing molecular rupture, has already been discussed. Occasionally in the solid state, the dissociation of a molecule may be followed quickly by recombination of the fragments, if they are scattered in close proximity. Some retention may arise on this account. Supposing, however, that the recoiling atom or radical escapes from the vicinity of the lattice-site at which capture takes place, then, after some dissipation of energy by dissociative collisions and lattice-penetration, it may dissociate another molecular ion and re-form a similar ion immediately afterwards, with the incorporation of the active atom or group. These last two effects are essentially similar, differing only in the special relation of the radioactive ion to the lattice-site at which capture occurred.

Two further modes of re-formation of the original molecular ion proceed independently of the slowing-down process. It has been found that the unknown species existing in the lattice can be induced to re-form the original molecular ion under the influence of very gentle heating or ionizing radiation [22]. At the same time, the effect of the latter on the inactive ions may lead to macroscopic decomposition. Since most neutron-irradiations are inevitably accompanied by

gamma-irradiation, both these effects will generally contribute to the retention.

Estimation of the retention involves the dissolution of the irradiated crystals and analysis of the solution; these procedures may, in certain circumstances, lead to re-formation of the original ions.

The extent of the increase in retention taking place on heating is a function of the temperature. The process does not exhibit a single activation-energy, but behaves as though several may be involved. Both the thermal- and radiation-induced increases in retention can be explained by either a radical or an electronic mechanism. On the former hypothesis, the thermal recombination corresponds either to the reaction of fragments diffusing into sufficiently close proximity, or to the reaction of the fragments with adjacent inactive ions. Either mechanism might be expected to involve several activation energies, depending on the nature and position of the fragments. Potassium chromate is remarkably resistant to radiation decomposition, so that, although dissociation of the chromate ion must often follow an ionizing event, recombination usually takes place. However, when dissociation in the vicinity of a recoil-fragment takes place, recombination may incorporate the active chromium atom. Thus, ionizing radiation may increase the retention by re-forming radioactive chromate ions while macroscopic reduction of inactive chromate ions is taking place. On the other hand, it is equally possible to

attribute both effects to electronic transitions [22].

The two contributions to the retention which are dependent on the scattering of the recoil-fragments might be expected to vary with the structure and collision-parameters of the irradiated crystal. In point of fact, the magnitude of this variation is greater than expected. By comparison of the retentions in the isomorphous anhydrous lithium, sodium, and potassium permanganates, under conditions such that the other four contributions to the retention must remain constant, it has been shown that a difference in retention of nearly 20 per cent. can arise from this source [21]. Such a structural dependence implies that the retention in solids might be critically dependent on the mean recoil-energy. Recent experiments have revealed such a variation. The retentions of two different radioactive isotopes generated by radiative-neutron capture in a single irradiation of a solid were found to be different [23]. Perhaps more important, comparison of the retention following the (n,γ) and (γ,n) reactions shows that the much larger recoil following the latter reaction leads, nevertheless, to a larger retention in the crystal [24].

Although qualitatively satisfactory interpretations of most of the effects have been advanced, the satisfactory identification of the mechanisms involved cannot be expected until more critical experiments have provided more accurate quantitative data.

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Some animal reactions to variations of temperature

WILMA GEORGE

Among the multifarious factors affecting living organisms, it is clear that temperature must be of great significance. There are, however, very considerable difficulties in distinguishing between effects due to variations in temperature alone and those brought about by a combination of causes. In this article the author describes a number of interesting animal reactions in which temperature appears to play an important, and perhaps a decisive, role.

The chemical processes of living organisms vary with the temperature of the environment, being slowed down by cold and quickened by warmth, though they may not closely follow the normal chemical laws in respect of their temperature coefficients. The limits within which animal life can exist are fairly wide. On raising the temperature, death occurs at somewhat below 50°C in normal adult multicellular animals, but the death-point at low temperatures is not known with any accuracy: it is considerably below the freezing-point of pure water. Until the critical temperature is reached, the effect of freezing is to slow down the life-processes to a minimum. Low temperatures can therefore be used for preserving living tissues.

The effects of extreme temperatures on individual organisms are not necessarily the same as those brought about by similar temperatures on the species as a whole. If the cold is severe, the effect on an organism from warm regions is to slow down the metabolic processes to such an extent that reproduction does not take place, and under such conditions the population cannot survive. On the other hand, if an organism from a cold climate is subjected to considerable heat it can, if it survive long enough, be stimulated to reproduce and thus possibly to establish the species in the new environment.

Since, other things being equal, the rate at which successive generations appear is relatively great in areas of high temperature, it must be supposed that the speed of genetic divergence in populations is proportionately increased. Among land vertebrates, a negative correlation has been found between the mean temperature and the number of species in the class. Rahn [5] counted 335 species of reptiles from temperate regions and 2785 from the tropics; similar figures, 948 and

2076 respectively, were found for mammals. It could be argued that this diversity depended largely on the greater availability of vegetation in tropical regions, but the evidence from the sea does not bear out this suggestion. Life in the sea is very abundant in the colder regions, owing mainly to the greater concentration and availability of nitrogenous compounds in cold water as compared with warm. Diatoms benefit directly, and they in turn support, directly or indirectly, very large populations of herbivorous and carnivorous animals. In spite of this abundance of food, the number of species of animals is small compared with the fauna of tropical waters. Of some 300 species of copepods, 80 per cent. come from warm seas, compared with only 5 per cent. from the cold northern seas.

Adaptations to life at different temperatures present for cold-blooded animals problems quite different from those encountered by warm-blooded vertebrates. For warm-blooded animals the problem is to maintain a steady internal temperature, while for other animals the life-processes must be adapted to function at the temperature of the surroundings. Few cold-blooded vertebrate species range from the Arctic to the tropics, but many have a considerable range within these extremes. Adaptations to low temperatures in species of the frog, *Rana*, include a greater resistance of the embryo to cold, and an increase in growth and metabolic rates compensating for the retarding effect of the low temperature [4]. Little is known of the physiological adaptations of invertebrates to life in the Arctic regions, but they are presumably similar to those shown by frogs. The remarkable fauna of insects and earthworms which lives in Arctic snowfields is characterized most obviously by uniformity of colour. Almost all the cold-blooded animals are black or of a very dark colour,

which may be an advantage in enabling them to absorb all available warmth from the Sun. Whether they have any mechanisms, either physiological or behavioural, to prevent rapid loss of heat, which would also be aided by dark colouring, is not known. The warm-blooded inhabitants of these regions, on the other hand, tend to be white, at least in winter; this may be considered an adaptation to prevent loss of heat from the body, though it may primarily be camouflage. Further general measures for conserving heat are the increase in the thickness of the fur in mammals and of the down-feathers in birds, and the use of thick layers of fat as an insulating material, as distinct from a food-reserve, in the whales and seals. Local increases in the complexity of the superficial blood-vessels, giving a larger surface for cooling, is frequently met with in animals of very hot regions. Habits, too, become adapted to the need for conserving heat in the Arctic and for keeping cool in the tropics. Many tropical animals spend the greater part of their lives in the shade, or are nocturnal, and desert forms are almost entirely nocturnal, in contrast to the diurnal habits of Arctic animals.

While some animals are to be found in almost every part of the world, in conditions ranging from those of the poles to those of hot springs, the ranges of different species vary greatly. Some have a wide range of temperature-tolerance, and members of such species are often geographically widespread. The raven, *Corvus corax*, is found from Greenland to the Sahara; the puma, *Felis concolor*, from Patagonia to Canada; the common toad, *Bufo vulgaris*, from Norway to Morocco. Other species are restricted to areas having a certain range of temperature: living corals occur only in warm seas at about 23° C, and the crustacean *Thermosbaena mirabilis* (figure 1) is restricted to certain hot springs in Africa, where it lives at some 48° C.

Within species found over a wide range of latitude, certain general adaptations to the hotter and colder parts of these ranges have been observed; this parallel evolution in response to the same environmental conditions has been enunciated in several biological rules having more or less widespread application [6]. It is, of course, not always easy to distinguish between direct adaptations to temperature and adaptations to conditions which are themselves dependent on temperature. The correlation between the temperature of the water and the size of the extensions of the body in planktonic invertebrates is an example. These

small animals have evolved spines, floats, and other body-extensions which increase their frictional resistance to the water and so mitigate the effects of gravity to the greatest possible extent (figure 4). In cold seas, the extensions of the body-surface are much less pronounced than in warm ones; these variations are presumably adaptations to the density of the water, which in turn is dependent on the temperature.

Variations in body-size within species of warm-blooded vertebrates having an extensive geographical range appear to be direct adaptations to the temperatures of the habitats. Bergmann's rule states that, in warm-blooded vertebrates, large body-size is directly correlated with cold climate. With increase in the size of a body, the surface-area, proportionate to the square of the dimensions, becomes relatively smaller than the volume, proportionate to the cube. Thus the larger the body the smaller the surface available for loss of heat, while the volume available for metabolic processes becomes larger. A small mammal like a mouse is in constant danger of becoming too cold; to compensate for its large radiating surface it needs to eat considerably more than its own weight of food in the course of a day. The cockatoo *Cacatua galerita triton*, which lives in the Malay Archipelago, shows significant regional variations in size. The populations which live on small flat islands in the tropical sea have a high proportion of small individuals, while those that live on large islands or in the mountains are composed for the most part of large individuals [3]. Similarly, the raven shows slight differences in size throughout its range, the largest individuals being found in Greenland.

A second rule, also applying to warm-blooded vertebrates, is due to Allen. Protruding body-parts are relatively shorter in individuals in the cooler parts of the range of a species than in the warmer areas. This too might well be an adaptation to prevent excessive loss of heat. Ravens from northern regions, for example, have shorter beaks than those from hot deserts.

Finally, there is Gloger's rule, which states that in the warm and humid parts of the range of a species individuals contain relatively more melanin. Reddish melanins prevail in arid regions and the blackish ones are diminished; in very cold areas the black ones also are reduced. Thus from the tropics to the Arctic, members of a given species would be expected to vary from predominantly yellowish or reddish, through black, to white. This rule has been found to apply to

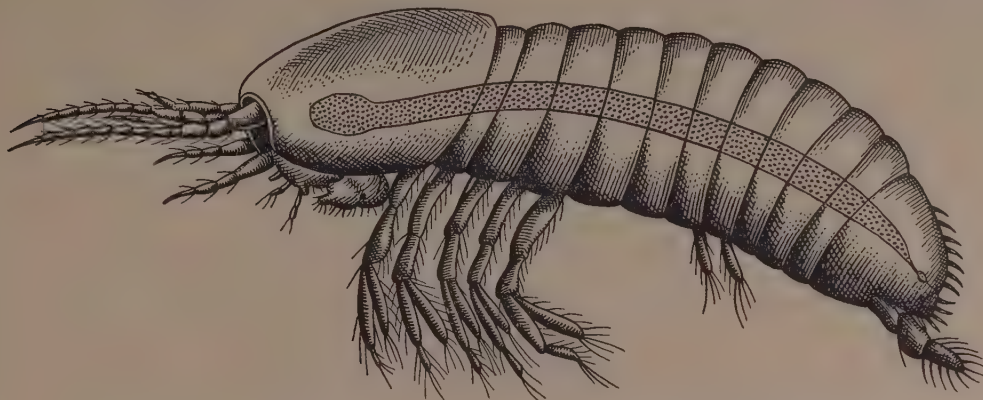


FIGURE 1 - *Thermosbaena mirabilis*, a crustacean restricted to certain African hot springs having temperatures of about 48°C . ($\times 36$)

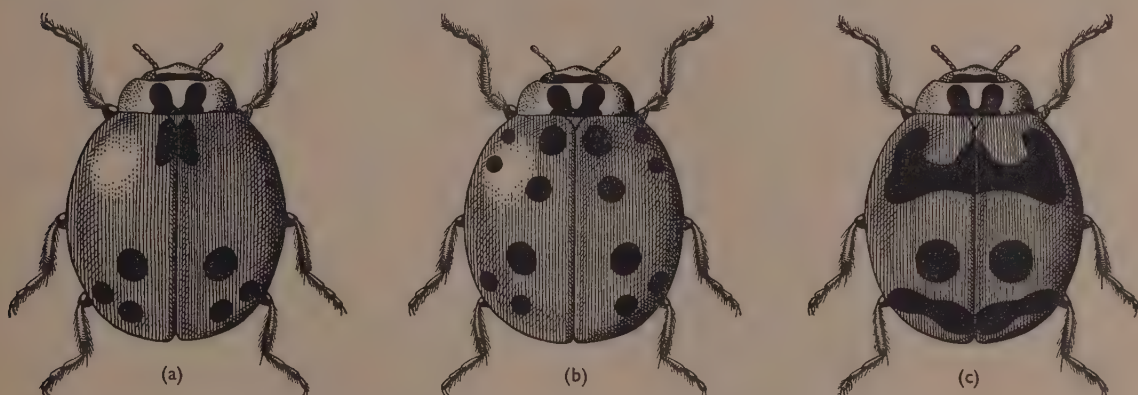


FIGURE 2 - *Ladybird, Adonia variegata*, (a) a light form, (b) the typical form, (c) a dark form. ($\times 8$)

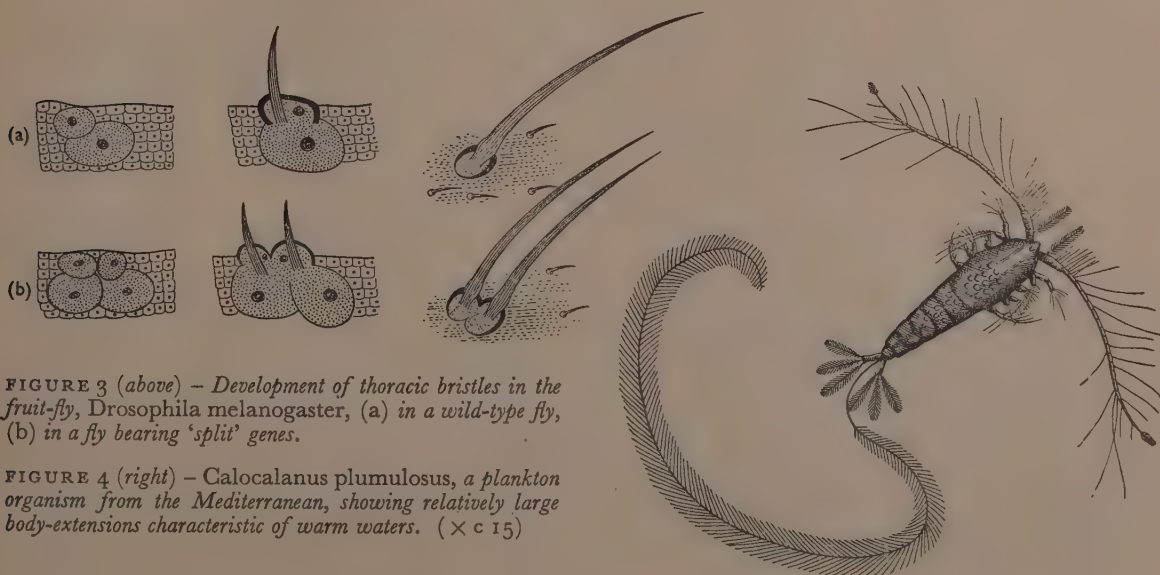


FIGURE 3 (above) - Development of thoracic bristles in the fruit-fly, *Drosophila melanogaster*, (a) in a wild-type fly, (b) in a fly bearing 'split' genes.

FIGURE 4 (right) - *Calocalanus plumulosus*, a plankton organism from the Mediterranean, showing relatively large body-extensions characteristic of warm waters. ($\times c 15$)

several species of birds and groups of insects. Dobzhansky [1] found that the colour-pattern of the elytra of coccinellid ladybird species varied according to the normal temperature of the habitat. Thus, the pale varieties of each species, red or yellow with few or no black spots, predominated in two centres, the hot arid deserts of Turkestan and Persia and the almost equally hot, dry regions of California, Arizona, and Mexico. As the temperature decreased with increasing distance from these centres, so more and more black-spotted individuals with, to some extent, more and more black spots were found. In Persia, the populations of *Adonia variegata* consist of 8 per cent. of individuals with the typical elytron pattern (figure 2*b*), and 1 per cent. of darker forms, while the rest of the population is composed of forms with rather few small black spots (figure 2*a*). The Siberian populations are very different, there being no lightly coloured individuals among them and only 18 per cent. of the typical form; the rest have confluent dark spots (figure 2*c*). The colour-patterns are inherited, and apparently depend on only a few genes.

The relative advantages of dark or light body-colour in hot climates depend to a great extent on the habits of the animals, and whether they are warm- or cold-blooded. Those animals which spend most of their lives in the open, or basking in the sun, are able to take advantage of all the available heat in the cooler parts of their range if, like the ladybirds, they are dark in colour. On the other hand, shade-haunting animals are, more suitably, darkest in the hottest areas of their range and thus able to lose excess of heat comparatively rapidly. As often happens in biology, it is clearly impossible to identify cause and effect here. Seasonal changes in the frequency of dark and light forms within a single population also occur among ladybirds, and these too may be adaptations to changes in temperature and in habits. Whether the temperature has a direct effect on the expression of the colour-pattern genes is not yet entirely clear. That temperature can have a pronounced effect on the expression of some genes has been clearly shown in *Gammarus chevreuxi*, the fresh-water shrimp. Ford and Huxley [2] showed that the normal black eye, and the less usual red eye, are dependent for their expression on an allelomorphic pair of genes, the black-eye gene being dominant to the red-eye. If forms bearing red-eye genes were reared at a high temperature, say 28° C, the eyes became black in twenty days; at 13° C, however, only a minute quantity of black

melanin was laid down and the eyes remained red. Conversely, young bearing black-eye genes, reared at 10° C, emerged from the brood-pouch with red eyes, which darkened slowly. The effect of the black-eye gene would thus appear to be similar to that of a comparatively high temperature; both seem to increase the velocity of a chemical reaction.

The expression of some genes, then, can be altered by temperature, and in at least a few cases the response of the genotype to the environment is apparently adaptive: hair-growth in mammals can be stimulated by low temperatures, and a cold, damp environment during pupal life may lead to darkening of the elytra of ladybirds. The definitive characteristics occurring in natural populations, however, are under the direct control of genes, and can be manifested without the stimulus of the external temperature. The normal genotype is, in fact, that which gives the maximum phenotypic adaptation under the prevailing conditions.

Other direct effects of temperature on the expression of genes are known experimentally. If insect larvae or pupae are subjected for a short time to temperatures outside their normal range they frequently show deviations from the normal phenotype. In the developing pupa of *Drosophila melanogaster*, for example, there comes a stage when certain cells destined to form thoracic bristles divide in such a way that, for each bristle, there is one cell to secrete the actual shaft and another to form the socket. A mutant form ('split') is known, in which the original bristle-cell divides twice and so produces two shafts and two sockets where normally only one of each exists (figure 3). A temperature-shock of 40° C administered for one hour in late larval or early pupal life gives a considerable proportion of phenotypically similar split bristles. It is as though either a mutant gene or an unspecific external agency can direct development down one path or another where an alternative exists. The changes produced by shock are changes in the phenotype and are not usually inherited. Whether they have any significance in animal evolution is open to doubt, though Waddington has suggested [8] that an environmental reaction of this type could eventually be taken over by a gene. The environment might so facilitate a particular pathway that when the requisite mutation occurred it could be turned to immediate advantage. On the other hand, these phenomena may rather be a sign of the general susceptibility of the organism to temperature changes. Well-established organisms whose natural

habitats have fairly uniform temperatures might be expected to have their development more easily upset by a sudden extreme of hot or cold than those organisms commonly inhabiting areas of very variable temperature. *Drosophila funebris* has races geographically differentiated in respect of temperature-resistance. West-European strains are susceptible to extremes of heat and cold, while strains from Russia are much more resistant [7].

Extremes of temperature are known to produce a small proportion of polyploid organisms. For example, low temperatures ($1.5-6^{\circ}\text{C}$) induce polyploidy in the American newt *Triturus viridescens*. The resultant triploids are almost certainly a dead end as far as evolution is concerned. In plants, on the other hand, polyploidy has been shown to be of considerable significance. It has been quite well established that polyploid plant species in general show greater resistance to cold than do their diploid relatives. There are many autotetraploids in the far north and in mountain regions: almost all the grasses of Spitsbergen are polyploids. It is not suggested that this is necessarily a direct response to the environment, but rather that these polyploids occurred as the climate was getting colder during the glacial epoch, and were able to establish themselves owing to their cold-resisting properties. How far polyploidy has been important in the evolution of hermaphrodite animals is still an open question.

Finally, temperature influences the rate of muta-

tion of genes. High temperature is correlated with a comparatively high mutation-rate. It is probable that this is a general reflection of the increase in velocity of chemical reactions, since a rise of 10°C increases the mutation-rate by about three times. A comparatively high mutation-rate may consequently be expected to occur in tropical countries unless selection has specifically reduced it.

Geographical differences in temperature are one of the underlying causes of diversity in the plant and animal kingdoms. Uniformity of temperature, both geographically and seasonally, would lead to a much more uniform flora and fauna than exist today. Temperature acts as a powerful selective agent on diverse populations of animals. It acts directly on the animal populations, since those individuals which cannot survive to reproduce their kind at a given temperature leave no descendants; it also acts by a more or less direct effect on the phenotypic expression of some genes. Indirectly, temperature selects animal populations through its more direct effect on vegetation, or on the availability of sources of plant food. Other things being equal, high temperatures favour more rapid evolution than do low ones, because of the increase in the rate at which new generations appear and the increase in the mutation-rate. A comparison of the number of species occurring in the tropics and in other regions of the world supports the contention that the tropics are the site of the most rapid evolution of animals.

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Book reviews

SCIENCE AND PHILOSOPHY

Philosophic Problems of Nuclear Science: Eight Lectures by Werner Heisenberg (translated by F. C. Hayes). Pp. 126. Faber and Faber Limited, London. 1952. 16s. net.

This volume contains eight lectures delivered to various learned societies between 1932 and 1948 on the philosophical, and to some degree moral, implications of quantum physics; in spite of the title, however, the lectures are by no means limited to nuclear physics.

As Heisenberg was one of the main founders of the quantum theory, anything that he has to say must command respectful attention, but in these lectures he shows that besides being a great artist in the application of mathematical ideas to the facts of physics, he is a wise and profound thinker on the philosophical consequences of the theories he has done so much to create. Perhaps not to create, but rather to discover, for he is at pains to point out a truth not always fully realized even by

able writers on these subjects, the peculiar, and at first sight rather repulsive, ideas of the quantum theory are not the gratuitous invention of a few able physicists. Rather were they forced on reluctant workers who had done their utmost to find what they regarded as a reasonable way out of what seemed hopeless contradictions, and who accepted the ideas of Heisenberg and de Broglie with avidity because their resistance to drastic change had been worn down by years of struggling with brute

facts which refused to fit into the old boxes. Physics has progressed by sacrificing old ideas about space and time and matter which seemed of the very nature of things. It will probably have to sacrifice yet more before the mystery of the nucleus is explained, and with it the true relation to one another of all these new so-called fundamental particles which are being discovered so rapidly and which transmute themselves into one another in such curious ways.

Heisenberg believes that the old determinism is gone for ever. He argues convincingly against the possibility of making a consistent scheme by the assumption of hidden deterministic laws which somehow simulate those of chance. I was specially struck by his very clear argument about an α -particle from radium which is then diffracted, for example by a crystal. If it really comes out deterministically at a definite time in a definite direction it must hit a definite part of the crystal lattice, and how then can this act as a grating? But he also believes that the classical physics of Newton retains a sort of pre-eminence because it is this that must describe the essential apparatus by virtue of which we can study phenomena, even atomic phenomena. This could perhaps be otherwise expressed by saying that there must be an 'interpretation' of the abstract multi-dimensional world of wave-mechanics into events in ordinary space and time before they can reach observation.

Heisenberg is an uncompromising atomist, and he discusses how these ideas arose in Greek thought and how they have been modified in ours. How qualities such as colour and taste disappear from matter regarded as congeries of hard atoms, but the latter at first retain shape and size. Now these properties too disappear, or at least become vague, and the atom, or rather the electron, becomes an entity without parts, shape, or size, as indeed it logically should. But surely Heisenberg is in error in implying that the ancient atomists expected all their atoms to be fundamentally the same? Lucretius, whose account, though late, is much the fullest, certainly did not, and he ascribed different properties to different atoms. He did indeed introduce a sort of Prout's hypothesis of integral atomic weights, but this was never carried to the point of supposing a single fundamental particle.

I wish Heisenberg, who speaks of Pythagoras, had laid more stress on the magic of whole numbers. More and

more it is becoming clear that the patterns, which seem likely to be all that is left of matter and energy when this chapter of physics is completed, are patterns characterized by whole numbers. The far-reaching philosophical conclusions which Pythagoras seems to have drawn from his experiments on the musical notes of strings were utterly unjustified by the facts at his disposal, but it is exciting to see him coming to the same ideas from studying the most elementary form of stationary vibration as we are now reaching from the study of states of atoms as described by wave-mechanics, whose mathematics is just a glorified form of that required to explain the notes of a lyre.

In the last lecture the difficulties of science and of scientists in a nationalistic state are discussed from the viewpoint of a patriotic German after the war had been lost. Heisenberg was addressing a student gathering and is at pains to show how he himself had learned to regard science internationally. He believes that, though an individual scientist may have great and difficult responsibilities in deciding how to apply his knowledge, the real use of science to the life of humanity is in providing a body of truth outside man's control—'there will always be a "right or wrong" in science. There is a higher power, not influenced by our wishes, which finally decides and judges.' Knowledge, in the long run, matters more than the standard of living.

G. P. THOMSON

IDENTIFICATION OF MINERALS

Welcher Stein ist das?, by Rudolf Börner. Pp. 165, with coloured plates. Kosmos-Gesellschaft der Naturfreunde Franckh'sche Verlagshandlung, Stuttgart. 1952. DM. 5.80 net.

This small volume, in the excellent nature-study series published by the Kosmos-Gesellschaft, will be of considerable use to geologists and mineralogists, but particularly so to students, because so much information is presented in a readily accessible form. More than 500 minerals are dealt with, including 280 gemstones. An important feature of the work is the provision of 14 excellent colour plates illustrating 160 minerals, rocks, and gemstones. In addition, there are 7 illustrations in the text and 16 tables.

Following a brief but good introduction, the various crystal systems are illustrated, with examples of modifications; 64 pages are then devoted to a

tabulated description of minerals, arranged primarily according to their colours and giving details of streak, specific gravity, fracture, cleavage, occurrence, and associates. A further table, arranged in groups according to the colour of the streak produced on porcelain, gives formulae and hardness.

An introduction to gemstones in general is given, with details of hardness-testing; there is a useful table of comparative hardness according to different scales. The various minerals used for hardness-indexes are listed, and comprehensive details of the hardness of minerals on Mohs' scale are given. Notes and tables on optical properties are followed by a table on the dispersive power of varieties of different minerals.

There is a short but fascinating section on the structure of the Earth, together with illustrations and tables giving details of the composition of various rock-building minerals and their occurrence. Following a final section on the properties of rocks used for structural and industrial purposes, a good index completes a very useful book.

ARTHUR MARSDEN

PETROLOGY FOR CHEMISTS

Rocks for Chemists, by S. J. Shand. Pp. xii + 146, with half-tone and line illustrations. Thomas Murby and Co., London. 1952. 21s. net.

Petrology is a difficult subject to explain to the non-petrologist, but Dr Shand has made a praiseworthy attempt to do so. After a short historical introduction, the author introduces the reader to rocks in the field, rock-forming minerals, the nature of active lava, the nature of underground lava, the classification of eruptive rocks, and the main types of eruptive rock. This is followed by a short chapter on the sedimentary rocks and two chapters on the metamorphic rocks. There are a list of suggestions for further reading, and a series of thirty-two photographic plates illustrating rocks in the field and their appearance under the microscope.

The book is addressed primarily to chemists and students of chemistry, for, as Dr Shand points out in the preface, petrology offers them a rich field for research. The writing is clear and concise and the subject is made interesting, but the book is not above criticism. The chapter on rock-forming minerals would be improved if more were said about the crystal structures of the minerals concerned, and it is not correct to say

(p. 15) that ferric iron may replace silicon in hornblende. In a book intended for chemists, the diagrams of three-component systems should be drawn in detail with their isotherms. Chemists would be interested in the mineralogical phase rule and the concept of facies in metamorphism, neither of which is mentioned, and surely in a work of this kind some attention should have been paid to geochemical research.

S. R. NOCKOLDS

DICTIONARY OF ENGINEERING

Dizionario d'Ingegneria, compiled by Eligio Perucca. Vol. I, A-CER, pp. xii + 1052, with 2200 figures; Vol. II, CER-FOR, pp. viii + 1087, with 2200 figures and one colour table. Unione Tipografica-Editrice Torinese, Turin. 1952. Lire 12,000 per volume.

Scientists and engineers who have to read foreign technical literature realize very soon that even the best technical dictionaries are inadequate, and that it is safer to consult a technical encyclopedia in the foreign language concerned. The work under review should thus be useful even outside Italy, as it apparently contains all the information that an engineer may require, explained in fairly simple terms. It is a beautiful publication on which much industry and care have been bestowed, and which reflects credit on both editor and publisher.

Important subjects are divided into paragraphs progressively numbered in Roman numerals, which indicate different branches of science, and in Arabic figures, which classify the material referring to a single branch. For example, 'Antenna' is divided into I Civil Engineering, II Naval Engineering, III Electrical Engineering. Section III is then subdivided into III = 0 General; III = 1 Linear antennae; III = 2 Current distribution along the antenna; III = 3 Polar diagram; and so on. Each paragraph is further divided into sub-paragraphs. Thus III = 2—0 Distribution of the current; III = 2—1 Deviations from sinusoidal form. In this way, some kind of subject index is provided and cross-references are made easy.

The standard of the work is high, as one might expect from the impressive list of contributors, and it appears to be generally up to date. Diagrams and figures are clear. The choice of subjects and the relative importance given to the various headings may be a matter of opinion. As is probably inevitable,

there are some repetitions and omissions. For instance, the modern crystal diodes are not mentioned either under *cristallo* or under *diodo*. A few mistakes have been noticed, e.g. the electronic charge as given in coulombs is ten times too small.

Despite these minor blemishes and the relatively high price, this is a work that should be in every engineering library.

L. PINCHERLE

CROP LOSSES

Untaken Harvest, by George Ordish. Pp. 171. Constable and Company Limited, London. 1952. 15s. net.

This well-written book contains a double challenge. The author, after a brief introductory chapter, plunges into the consideration of losses caused by pests and diseases. He makes no attempt to cover up the lack of accurate information or the difficulty of interpreting the existing data in monetary terms. Because, however, the evidence has been examined critically and set out clearly, the figures given for losses are the best statement so far published.

The author next discusses, so far as the evidence permits, the relationship between the reduction in loss and the cost of different treatments. He draws the conclusion that far more precise data on the incidence of, and damage done by, pests and diseases will be required before sound advice can be given on the amount that can be justifiably expended on treatment. This is the first challenge. He does, however, succeed in tabulating the evidence available in a way which should be very useful to farmers and growers. Allowing for the inaccuracy of the evidence, he makes out an overwhelming case for the extension of the present level of treatment. Losses of over £70,000,000 a year cannot be allowed to continue. That is the second challenge.

In another well-presented chapter Ordish discusses the claim that pests and diseases, by reducing yields, are the growers' friends, and he shows that this is in general untrue.

This is a most readable book and at the same time a valuable work of reference.

W. SLATER

COLOUR

Colour in Theory and Practice, edited by H. D. Murray. Pp. xiii + 360, with colour, half-tone, and line illustrations. Chapman and Hall Limited, London. 1952. 70s. net.

This attempt by eight specialists, in-

cluding the editor, to deal with all aspects of colour—the physics of radiation, light sources and light detectors, the chemical structure of dyes, the human visual apparatus and its reaction to light and colour in both normal and colour-defective people, the technical details of photometry and colorimetry, and the emotional response to colour in everyday situations—is on the whole successful. There are three classes of reader to whom the book should prove valuable: students of physics, chemistry, or physiology needing to learn something of the whole subject of colour, research workers immersed in one type of colour problem but necessarily interested in related subjects, and the technical man encountering some question involving colour, to deal with which he must quickly acquire a background of specialist knowledge. The depth of treatment varies widely—one chapter is devoted to elementary optics, for example, but another introduces the relatively advanced chemical concepts of molecular orbitals, hybridization, and conjugation. There is some overlapping, particularly in the treatment of trichromatic ideas, and not much attempt is made to weld together the contributions of the different authors. These objections are probably unimportant in a book which no doubt will be used largely as a work of reference. Its value is increased by appendices on colour terminology, colorimetric data, and the properties of colouring matters of natural and synthetic origin.

W. S. STILES

DETONATION OF EXPLOSIVES

Detonation in Condensed Explosives, by J. Taylor. Pp. 196, with line and half-tone illustrations. Oxford University Press, London. 1952. 25s. net.

The publication of this book, dealing with the mechanism of detonation in condensed explosives, is particularly welcome, since much of the matter with which it is concerned has not hitherto been readily accessible, being distributed among papers in different journals and various wartime reports. The understanding which has been attained of the dynamical and thermodynamical aspects of detonation in solid explosives is to a large extent a result of the scientific war effort of Britain and the United States. Many difficulties had to be overcome in order to adapt the dynamical theory of detonation in gases, developed at the beginning of

this century, to the detonation of condensed explosives. This book gives a clear and straightforward account of these developments, and of the many advances which have been made since the end of the war. Many of the experimental results relating to industrial explosives, and the adaptations of general theory to such explosives, have come from the work of Dr Taylor himself and the members of his staff.

Although important experimental techniques are dealt with in this book, the greater part of it is concerned with the physical theory of the detonation process. The thermochemistry of the products of the explosion is fully discussed on the basis of various plausible equations of state, and numerous tables, the result of lengthy calculations, are given; these should be of great value to all engaged in this branch of research. There is also much to interest the general reader, for the theory, with regard to both the firmness of its foundations and, in some respects, the neatness of its mathematics, compares favourably with many aspects of the theory of the solid state. H. JONES

STEREO-PHOTOGRAPHY

Stereo Photography in Practice, by E. F. Linssen. Pp. 326, with line diagrams. The Fountain Press, London. 1952. 42s. net.

Comparatively few books have been written on stereo-photography, and practically no authoritative ones in recent years. The appearance of a new treatise is therefore something of an event, and especially so when it is as exhaustive and well documented as Mr Linssen's.

Stereoscopy first became popular about the middle of the last century; by 1856 no fewer than half a million stereoscopes were in use, and no drawing room of the period was complete without one. Unfortunately, however, the popularity of the three-dimensional photograph led to its commercial exploitation in sometimes undesirable form, and stereoscopic photography fell into disrepute.

Though a few enthusiastic photographers kept the practice alive, this fascinating and highly specialized branch of photography has taken nearly a hundred years to live down the reputation it acquired in mid-Victorian times.

This has been unfortunate, because stereo-photography can perform many useful functions apart from its pictorial one. Mr Linssen discusses most of them, as well as dealing exhaustively

with both the theory and the technique of producing stereograms, and the design of cameras and viewers. Some space is devoted to three-dimensional motion-pictures, but as the author remarks, '... as far as practicable stereo cinematography is concerned, we are still in its experimental stage.' Autostereoscopy by both grid and lenticular systems, which have obvious potentialities in the motion-picture field, as well as elsewhere, are considered in the same chapter.

Mr Linssen's book is as nearly a complete treatise as anyone could expect within 300 pages. It is certainly the most informative book on the subject available.

P. A. LE NEVE FOSTER

ANTIBIOTICS

Antibiotics: A Survey of their Properties and Uses. Pp. 274 + ix. The Pharmaceutical Press, London. 1952. 25s. net.

This comprehensive volume deals with the common antibiotics, primarily from the standpoint of the pharmacist. The work of the variously qualified contributors has been well planned, and between them the fields of chemistry, manufacture, experimental investigation, clinical, medical, and veterinary use, and legal aspects are well covered.

In any volume such as this, points must inevitably become out of date even before publication; thus the toxicity of chloroamphenicol would now need further treatment, in view of recent publications.

The section describing synergism and antagonism deals briefly with some of the experimental work done in this field. Many workers would not be satisfied that the profuse infections with *Candida albicans* seen in patients having penicillin treatment are solely due to the suppression of the normal flora.

On the whole, the section on experimental work is less uniformly excellent than the rest of the volume, but nevertheless this book will be invaluable to many for reference. Its wide scope and excellent bibliography will certainly mean that most readers will find something new.

The statement that *Streptococcus pyogenes* has been reported as a producer of penicillinase will confuse some who do not realize that this is a misprint for *Staphylococcus pyogenes*. R. M. GALMAN

DETERMINATION OF CRYSTAL STRUCTURES

International Tables for X-ray Crystal-

lography, Volume I, Symmetry Groups, edited by N. F. M. Henry and K. Lonsdale. Pp. xii + 558, with 237 figures and glossary in five languages. Published for the International Union of Crystallography by The Kynoch Press, Birmingham, England. 1952. £5 5s. net.

X-ray crystallographers are immensely indebted to those responsible for this new work, which supersedes the 1935 'International Tables for the Determination of Crystal Structures.' Much of the earlier material is retained, but a new work has emerged with the avowed and achieved aim of helping not only those engaged in crystal structure determination but students and all who apply X-ray methods to crystals. Consequently there has been a change of name and of content. This first volume, dealing with crystal lattices, point-groups, and space-groups, has, apart from the main tables, sections on numerous aspects of symmetry determination.

For accurate use, space-group diagrams and associated matter must be large. Accordingly, geometrical structure factors and electron density functions are separately tabulated, and for the chief space-group descriptions the general rule has mainly been 'one space-group, one page.' When, in a few instances, the attempt is defeated by long lists of equivalent positions, the diagram and tabular matter are, with a few insignificant exceptions, arranged within the limits of two facing pages. A very slight infirmity of purpose in this respect is detectable on p. 250, where P_{31} and P_{32} , which, as enantiomorphs, might have faced each other, are found together. This perhaps leads to the difficulty on p. 253, but the editors quickly recover their resolution and avoid what would have been an infuriating turn of the page by boldly continuing p. 253 in the space conveniently available at the foot of the preceding page. A page or two further on it becomes apparent that this was done so that later sets of enantiomorphs or other related pairs should again face each other. Such attention to detail includes a reversed order of headings on left and right pages, so that the right-hand space-group symbol is not lost in the curve of the page. A welcome improvement is the alternative setting for monoclinic space-groups with the unique axis taken as z . The little-used diagrams for cubic space-groups have been omitted.

The language used throughout is English, but there is a short glossary

giving French, German, Russian, and Spanish equivalents. This is limited strictly to crystallographic terms, and except for a word or two includes nothing that does not occur in the text of Volume I. Volumes II and III will have their own glossaries.

The Kynoch Press is to be congratulated on its contribution to the elegance of the product.

H. M. POWELL

SIR JAMES JEANS

Sir James Jeans: A Biography, by the late E. A. Milne. Pp. xvi + 176. Cambridge University Press, London, 1952. 21s. net.

The work of Sir James Jeans was of such importance for the development of scientific thought in his day that it is fitting that his biography should be published. His first interests were in the problems of the dynamical theory of gases and the partition of energy, culminating in the important 'Report on Radiation and the Quantum Theory' (1914), which did much to establish confidence in the quantum theory and in Bohr's theory of the atom. There followed a period of great constructive achievement. Jeans turned his attention to the forms of equilibrium and the stability of rotating gravitating fluid masses, a problem of considerable mathematical complexity. This work led him to consideration of the problems of cosmogony, and these investigations were collected and summarized in his 'Problems of Cosmogony and Stellar Dynamics' (1919) and 'Astronomy and Cosmogony' (1928). Milne rightly describes the first of these as a classic in astronomy; the later work, though planned on a more comprehensive scale, was less successful and is not of such permanent value.

After 1928, Jeans abandoned original research and occupied himself with writing a series of popular expositions of astronomical and physical science, and of the philosophical implications of the new developments in scientific thought. Mr S. C. Roberts, of the Cambridge University Press, in a memoir which forms a foreword to this biography, describes how Jeans, at his suggestion, came to undertake the writing of popular books, and gives a delightful sketch of Jeans as a man.

Milne says that Jeans never wrote a dull page of mathematics in his life. His scientific writings are characterized by great attractiveness and a natural beauty of style. It was these qualities, combined with clarity of exposition,

aptness of simile, and width of knowledge, which were responsible for the extraordinary success of his popular books. The arousing of a widespread interest in fundamental problems of science was not the least important of Jeans' achievements.

H. SPENCER JONES

CAPTAIN COOK

Captain Cook, by Christopher Lloyd. Pp. 172, with half-tone illustrations. Faber and Faber Limited, London. 1952. 10s. 6d. net.

During the last twenty years there has been a spate of biographies of Captain Cook, and it might be thought that there was no occasion for another. But, as Mr Lloyd reminds us, none of the earlier ones remains in print, and there is certainly room for a biography aimed at the reader who knows little or nothing of the subject. For such a reader it is essential that the objectives underlying each of Cook's three voyages and the extent to which they were achieved should be fully explained, and here the author has been conspicuously successful. He has been equally successful in the difficult task of condensing all the essentials of Cook's life into 172 pages. For the class of reader for whom it is intended his book is eminently suitable.

There are a few minor errors, e.g. as to the number of unauthorized accounts of the first voyage and the date of Captain Gore's death, but there is also one of consequence, viz. the resuscitation of Kippis's erroneous statement, for which he was taken to task by Joseph Banks, that America refused to follow France in granting immunity from capture to Cook's ships on the third voyage.

MAURICE HOLMES

THE BIBLICAL FLORA

Plants of the Bible, by H. N. and A. L. Moldenke. Pp. xx + 364, with 95 illustrations. Chronica Botanica Company, Waltham, Massachusetts; William Dawson and Sons Limited, London. 1952. \$7.50 net.

When Mary Cowden Clarke had written the last words of her 'Concordance to Shakspeare,' she doubtless and with justice felt that she had accomplished a useful task that no one need ever undertake again. The authors of 'Plants of the Bible' must have experienced a similar feeling on arriving at *Zizyphus* and *Zostera* after the long journey from *Acacia* and *Acanthus*. Mrs Clarke, however, though of grateful

memory, needed no equipment but industry and accuracy, and a junior clerk could have compiled the 'Concordance' equally well, given sufficient immunity from boredom. Dr and Mrs Moldenke required, and clearly possess, additional qualifications of a very different order: scholarship, both in the narrow sense of the word and in the sense of a profound knowledge of their subject-matter, together with a critical judgment to sift the copious relevant literature. It may at once be said that their book will supply, for many years, all the important—and much of the detailed—information about Biblical plants that botanists, theologians, and readers in general are likely to seek.

The passages in which the various plants are mentioned are given at the head of the appropriate sections, and are followed by botanical, historical, and other references. There are also numerous illustrations, many in half-tone, as well as a general index and an index of Biblical verses. The book is written in an attractive style, and anyone dipping into it will probably read on and on. It is altogether a sound and very useful piece of work, for which Dr and Mrs Moldenke deserve our thanks. If we have a criticism, it is that the authors have been too anxious that nothing shall be omitted. A verse in Joshua, for example, saying that 'our bread . . . is mouldy,' is made an occasion for dragging in *Mucor mucedo* by the back hyphae, and it comes as something of an anticlimax to be told later that the word translated as mouldy may really mean crumbling.

E. J. HOLMYARD

COLOURED GLASSES

Coloured Glasses, by Woldemar A. Weyl. Pp. 541, with line diagrams. The Society of Glass Technology, Sheffield. 1951. 25s. net.

Professor Woldemar Weyl has for the last twelve years devoted himself to research into the structure and constitution of glass, with special reference to colours and light-absorption. The present book breaks new ground, for no comparable one on the subject has appeared previously. In addition to presenting the results of his own very fruitful researches, the author examines and correlates the extensive data that have become available from a variety of sources in recent years.

Weyl has considered coloured glasses from the point of view of the physical chemist. Earlier research workers in this field have seldom attempted to give basic explanations of their results, but

Weyl has sought to provide an understanding of the fundamentals of the subject, and especially to explain precisely why the colour of glass differs from one melt to another. His treatise is a brilliant one, absorbingly interesting to read, and of high permanent value as a work of reference.

This work fills an important gap in the literature. With characteristic breadth of outlook the author rightly claims that the chemistry of glasses offers a sound basis for that of fused salts in general, and especially for that of metallurgical slags.

L. M. ANGUS-BUTTERWORTH

VALENCE

Valence, by C. A. Coulson. Pp. x + 338. Oxford University Press, London. 1952. 25s. net.

This book was written to describe the contributions which wave mechanics has made to our understanding of valence. No previous knowledge of wave mechanics is assumed, but many of its more technical principles are explained and then utilized, without, however, an attempt to give a complete background of the theory of quantum mechanics. This, of course, imposes a definite limit on the depth of the understanding which a reader can expect to acquire from the book. Within this limit, Professor Coulson has accomplished his aim in a superlative fashion.

The text has a number of special virtues. It is written in a clear and interesting style. The two main theories of valence—the valence bond and molecular orbital theories—are given equal emphasis, instead of being regarded as competitors each seeking adherents at the expense of the other. The treatment is up to date and more critical than in earlier books on the subject. The author does not hesitate to emphasize the seriousness of the assumptions which the theory often forces one to make, but the reader should not be discouraged by such procedure, for it is shown that the magnitudes of the errors introduced by the assumptions can often be estimated.

WÄLTER KAUFMANN

SCIENCE AND LITERATURE

Literature for an Age of Science, by Hyman Levy and Helen Spalding. Pp. 247. Methuen & Co. Limited, London. 1952. 15s. net.

The reader who expects to find much about the influence of a scientific age on current literature will be disappointed in this book; for that, the

authors are not to blame, because the title not inaccurately indicates their general theme. They contend that, in an age where society is obviously maladjusted to science and technology, literature can and should play a much more important part than it does in pointing the way 'to an integration of the achievements of science with the emotional life of man.' In the opinion of the authors, the great literature of the past has always been too individualistic, and a class-product which has failed to heighten the social awareness and to unify the outlook of all classes of society. Even Shakespeare, they say, has not done justice to the lower orders, whom he treats as figures of fun. Bernard Shaw saw clearly the social defects of his time, but with the head rather than the heart, and Galsworthy, in spite of his interest in social injustices, 'plays safe . . . by appealing to the liberal sympathies of his audience without offending them.' Recent literature has not only failed to fulfil its proper function, but, they say, has even assisted the decadent process.

The book, which the authors classify as literary criticism, is highly analytical and demands concentrated attention. Most readers will probably find the chapters on poetry, the novel, and the drama the most interesting, but even in them a light touch is absent. The heaviness of the style is aggravated by the frequent use of such phrases as 'canalized by social forces,' 'the poetic totality of the disillusionment of love,' 'summed in the present,' and many others. It is a little surprising to note a reference to Shakespeare's use of the language of Elizabethan coffeehouses.

The book is heavy and provocative, but presents a viewpoint which cannot be ignored.

J. K. ROBERTSON

BIOLOGY OF HOT SPRINGS

Grundriss zu einer Balneobiologie der Thermen, by Vale Vouk. Pp. 88. Birkhäuser, Basel. 1950. Sw. fr. 14.55.

By balneobiology is meant the biology of hot springs in relation to their therapeutic use. The present account seems to be the first of its kind, and, although it does not deal with effects on the human body, it covers a wide field and gives much welcome information.

The peculiar natural plant and animal life of hot springs is to a great extent destroyed when the springs have to be enclosed in order to be used for medical purposes. In his own country,

Jugoslavia, the author had ample opportunity to study at first hand the biological communities of hot springs. He divides springs warmer than surface water into groups according to their temperature and vegetation, and emphasizes that the former is almost constant. The hottest, even up to 85° C, are inhabited by blue-green algae, the most characteristic being *Mastigocladus laminosus*, but there are in addition special thermophilic sulphur- and iron-organisms; at lower temperatures other algae are present.

The present state of balneobiology is characterized by the fact that, in spite of the fascinating and very important general and practical problems involved, of which the book gives a good idea, there is no reference to any experiments with organisms from hot springs, although a few have in fact been carried out. The author suggests an explanation of the therapeutic properties of the waters based on the observation that autoclaved water has an effect on seedlings similar to that of water from hot springs.

E. G. PRINGSHEIM

PHOTOGRAPHIC EXPOSURE

Exposure Meters and Practical Exposure Control, by J. F. Dunn. Pp. 252, with colour, half-tone, and line illustrations. Fountain Press, London. 1952. 35s. net.

This volume covers the basic principles governing estimation of photographic exposure rests.

Since integrating photoelectric meters were marketed many photographers have purchased them, but few have realized that the judgment necessary in their use is almost as great as that necessary to obtain an accurate result from exposure tables on a calculator. Failure at low levels of illumination renders these instruments useless just where help is most needed. The newer 'incident type' meter, measuring the light intensity at the subject, is considerably more accurate in its own field of colour and reversal work, but nevertheless the only type of instrument with which exposure determination can be reliably carried out is the photometer. The author originally described, with G. S. Plant, one of the most successful photometers now available, and he is therefore well able to explain the use of this type of instrument and its principles. The volume can be recommended as a judicious combination of the practical and the theoretical approach.

R. M. CALMAN

Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Agricultural Chemistry, Volume II: Practical Applications of Agricultural Chemistry, by Donald E. H. Frear. Pp. 588. D. Van Nostrand Company Inc., New York; Macmillan and Company Limited, London. 1951. 71s. net.

Manures and Fertilizers, by A. M. Smith. Pp. 275. Thomas Nelson and Sons Limited, London. 1952. 15s. net.

ASTRONOMY

The Creation of the Universe, by George Gamow. Pp. 147, with line and half-tone illustrations. The Viking Press, New York; Macmillan and Company Limited, London. 1952. 21s. net.

The Sky and its Mysteries, by E. Agar Beet. Pp. 238, with half-tone and line illustrations. G. Bell and Sons Limited, London. 1952. 15s. net.

BIOCHEMISTRY

Biochemical Preparations, by E. G. Bell. Pp. 109. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 24s. net.

The Comparative Biochemistry of the Carotenoids, by T. W. Goodwin. Pp. 356. Chapman and Hall Limited, London. 1952. 50s. net.

The Metabolism of Protein Constituents in the Mammalian Body, by S. J. Bach. Pp. 272. Oxford University Press, London. 1952. 40s. net.

BIOGRAPHY

Hamey the Stranger, by John Keevil. Pp. 192, with half-tone illustrations. Geoffrey Bles, London. 1952. 21s. net.

Antoine Lavoisier: Scientist, Economist, Social Reformer, by Douglas McKie. Pp. 335, with half-tone and line illustrations. Constable and Company Limited, London. 1952. 30s. net.

Abraham Trembley of Geneva, Scientist and Philosopher, 1710-1784, by John R. Baker. Pp. 259, with half-tone and line illustrations. Edward Arnold and Company, London. 1952. 35s. net.

BIOLOGY

Morphogenesis: An Essay on Development, by John Tyler Bonner. Pp. 296, with line and half-tone illustrations. Princeton University Press, Princeton, New Jersey; Oxford University Press, London. 1952. 32s. net.

Traité de Paléontologie, edited by Jean Piveteau. Volumes I and II. Pp. 782 and

790 respectively, with half-tone and line illustrations. Masson et Cie., Paris. 1952. Vol. I, paper-covered 8300 fcs., bound 8900 fcs. Vol. II, paper-covered 9000 fcs., bound 9700 fcs. net.

BOTANY

Developmental Plant Anatomy, by Richard A. Popham. Pp. 361, with half-tone and line illustrations. Long's College Book Company, Columbus, Ohio. 1952. \$4.50 net.

CHEMISTRY

Fundamental Principles of Polymerization, by G. F. D'Alelio. Pp. 517, with line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 80s. net.

Hydrogen Ion Concentration: New Concepts in a Systematic Treatment, by John E. Ricci. Pp. 460. Princeton University Press, Princeton; Oxford University Press, London. 1952. 63s. net.

An Introduction to the Chemistry of the Hydrides, by Dallas T. Hurd. Pp. 221. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 44s. net.

Maleic Anhydride Derivatives, by Lawrence H. Flett and William Howlett Gardner. Pp. 269. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 52s. net.

Progress in the Chemistry of Fats and other Lipids, edited by R. T. Holman, W. O. Lundberg, and T. Malkin. Pp. 186, with line and half-tone illustrations. Pergamon Press Limited, London. 1952. 42s. net.

Styrene: Its Polymers, Copolymers and Derivatives, by R. H. Boundy and R. F. Boyer. Pp. 1304, with half-tone and line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1952. 160s. net.

GENERAL

Handbook of Scientific Instruments—H.M. King George III Collection. Descriptive catalogue, by J. A. Chaldecott. Pp. 92, with half-tone illustrations. Her Majesty's Stationery Office, London. 1952. 7s. 6d. net.

Manual of Photogeography, by Léon Croizat. Pp. 587, with maps and line drawings. Dr W. Junk, The Hague. 1952. Fl. 45 net.

Studies in Conservation, edited by F. I. G. Rawlins. Vol. I, No. 1, October 1952. Pp. 47, with half-tone and line illustrations. Journal of the International Institute for the

Conservation of Museum Objects. Thomas Nelson and Sons Limited, London. 1952. 21s. net.

GEOLOGY

Histoire Géologique de la Biosphère, by Henri Termier and Geneviève Termier. Pp. 721, with maps and half-tone and line illustrations. Masson et Cie., Paris. 1952. Paper-covered 8600 fcs., bound 9200 fcs. net.

PHYSICS

Advanced Experiments in Practical Physics, by J. E. Calthrop (2nd ed.). Pp. 142, with line and half-tone illustrations. William Heinemann Limited, London. 1952. 10s. 6d. net.

Computing Methods and the Phase Problem in X-Ray Crystal Analysis, edited by Ray Pepinsky. Pp. 390, with half-tone and line illustrations. The Pennsylvania State College, Pa., 1952. \$7.50 net.

Harwell: The British Atomic Energy Research Establishment 1946-51. Pp. 128, with half-tone and line illustrations. Her Majesty's Stationery Office, London. 1952. 6s. net.

Journal of the Mechanics and Physics of Solids, edited by R. Hill and W. M. Baldwin. Vol. I, No. 1, October 1952. Pp. 76, with half-tone and line illustrations. Pergamon Press Limited, London. 1952. £4 10s. per volume (four numbers).

Superconductivity, by D. Shoenberg. Pp. 256, with line diagrams. Cambridge University Press, London. 1952. 30s. net.

Theoretical Nuclear Physics, by John M. Blatt and Victor F. Weisskopf. Pp. 864, with line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1952. 100s. net.

Theory of Electric Polarization, by C. J. F. Böttcher. Pp. 492. Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London. 1952. 70s. net.

Thermodynamique, by Y. Rocard. Pp. 551, with line diagrams. Masson et Cie., Paris. 1952. Paper-covered 3650 fcs., bound 4150 fcs. net.

ZOOLOGY

Animal Forms and Patterns, by Adolf Portmann. (Translated by Hella Czech and illustrated by Sabine Baur.) Pp. 246, with line illustrations. Faber and Faber Limited, London. 1952. 25s. net.

The Genetics of the Dog, by Marca Burns. Pp. 122, with half-tone illustrations. Commonwealth Agricultural Bureaux, Slough, Bucks. 1952. 12s. 6d. net.

Notes on contributors

J. W. CORNFORTH,
M.Sc., D.Phil.,

Was born at Sydney, Australia, in 1917 and was educated at Sydney High School and the Universities of Sydney and Oxford. Is a member of the scientific staff of the Medical Research Council, and has published many papers on organic chemistry and its application to biological problems.

E. N. DA C. ANDRADE,
D.Sc., Ph.D., LL.D., F.R.S.,

Was born in London in 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory at Cambridge. In 1928 he was appointed Quain Professor of Physics in the University of London. He served as an artillery officer in France in the war of 1914-18, and afterwards was for some years professor at the Artillery College (later the Military College of Science). At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state, which he built up again after his laboratories had been completely destroyed by bombs in September 1940. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He has a well known collection of early books on the exact sciences, and is an authority on Newton and his contemporaries. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences*. He is known for the clarity of his exposition of science both in writing and by lectures.

W. O. JAMES,
M.A., D.Phil., F.R.S.

Born 1900, and educated at Tottenham Grammar School and the Universities

of Reading and Cambridge. Reader in Plant Physiology, department of botany, Oxford, and Director of Oxford medicinal plants scheme. Editor of 'The New Phytologist.' Has published work on the nutrition and respiration of plants and on the metabolism of alkaloids in the *Solanaceae*.

MAX VACHON,
Docteur-ès-Sciences, F.Z.S.,

Was born at Dijon in 1908, and studied at the Faculty of Science at Dijon and later at the Sorbonne, obtaining his doctorate in 1938. Since that date he has worked under Professor L. Fage, *Membre de l'Institut*, as pupil and collaborator, studying one of the rich zoological collections of the *Muséum National*. His work deals principally with the relationship of systematics and taxonomy to morphology, embryology, and biology, particularly in the chelicerates and myriapods. Since 1948 has been *Maître de Recherches* at the *Centre National de la Recherche Scientifique*, and member of the *Comité National du C.N.R.S.* in the section of zoology and animal biology. He has collaborated in Professor P.-P. Grassé's *Traité de Zoologie*, in sections dealing with the orders scorpions, *Solifugae*, and pseudo-scorpions. A recent work, *Études sur les Scorpions*, has been awarded a prize by the *Académie des Sciences*.

A. KATCHALSKY,
M.Sc., Ph.D.,

Was born in 1913 and is a graduate of the Hebrew University, Jerusalem. His interest was early focused on the physico-chemical aspects of biological phenomena. While an assistant at the Hebrew University, he published some papers on the interaction of sugars with amino acids and peptides. Since 1947 he has been occupied with the study of

polyelectrolytes as models of biocolloid behaviour. His publications include papers on the general theory of polyelectrolyte solutions, the physical behaviour of solutions and polyelectrolyte gels, and mechano-chemical systems. Is at present head of the polymer department of the Weizmann Institute of Science, Rehovoth, and professor of physical chemistry at the Hebrew University. Elected scientific chairman of the Weizmann Institute for 1952-3.

A. G. MADDOCK,
M.A., Ph.D., D.I.C.,

Was born in 1917, and was educated at Upper Latymer School, London, and at the Royal College of Science. He spent the first two years of the war on chemical defence problems. He subsequently joined the staff of Imperial Chemical Industries Limited and was seconded to a team of workers attached to the Department of Scientific and Industrial Research. After spending nearly four years in Canada, he returned at the end of the war to take up a temporary position in the Ministry of Supply, in connection with the Atomic Energy Research Establishment. The following year he accepted an appointment in the University of Cambridge, where he still is. His interests cover most aspects of radiochemistry.

WILMA GEORGE,
M.A.

Born in 1918. After reading zoology at Lady Margaret Hall, Oxford, she went to Cambridge in 1941 and began research on the effects of high temperatures on *Drosophila*. 1942-5 was a member of operational research section, Coastal Command, Royal Air Force. Is now lecturer in zoology at Lady Margaret Hall. Author of *Elementary Genetics*.

ENDEAVOUR

The British quarterly scientific review ENDEAVOUR was first published in January 1942. Its purpose was to enable men of science, and particularly British men of science, to speak to the world in an hour when not only nations but the internationalism of science suffered the dangers of warfare. For the better fulfilment of this purpose ENDEAVOUR was from the first published in four separate editions—English, French, Spanish, and German. An Italian edition has been published since January 1948. Today the situation is happily different, but there can be no lasting peace without full and sincere co-operation between nations in every realm of human enterprise. In the scientific field ENDEAVOUR can thus play as useful a part in peace as it did in war, and for this reason the decision has been taken to make its publication permanent.

ENDEAVOUR is distributed without charge to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

